ELEMENTARY

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ELEMENTARY
HUMAN PHYSIOLOGY

BY

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WITH 164 *WOODCUTS*

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PREFACE.

TWENTY years ago, I wrote for Messrs W. & R. Chambers a small Manual on Animal Physiology. The present work is based on that book, but the chapters have been almost wholly rewritten, and they have been rearranged to suit the Syllabus of the First or Elementary Stage issued by the Department of Science and Art. The publishers have been able to place at my disposal a larger number of illustrations than are usually met with in an elementary work; and I would point out to both teachers and pupils that much valuable information may be derived by a careful study of the descriptions of the woodcuts. To aid in testing the advancing knowledge of the pupil, numerous questions have been introduced, usually at the close of a chapter, and reference is made to the paragraph where an answer may be found.

The general scope of the work and a statement of my notions as to how Elementary Human Physiology may be effectively taught in a school, will be found in the following extracts (with emendations) from the preface to the book on Animal Physiology.

It is now universally admitted that an acquaintance with the principal phenomena manifested by living beings, and more especially with the structure and mode of action of the different parts of the human body, is one of the most important branches of knowledge for men and women in all conditions of life. It is, therefore, no longer necessary to advocate the study of Physiology as a part of general education.

The object of the present text-book is to aid in this work. It professes to give such an account of the general mechanism and functions of the human body as ought to be known by every well-educated person. While aiming at brevity and clearness, the author has not attempted to avoid the use of technical terms, because such terms frequently express in a word a meaning which can only be conveyed in familiar language by circumlocution, and with the risk of vagueness. Many of the best of these terms have been handed down to us for generations, and they have become clear and definite symbols of thought. To attempt to teach a science without them will simply result in giving the pupil vague and superficial notions, so that if he should be obliged again to study the subject with the view of entering one of the professions for which it forms a special branch of training, he will find that he has to learn the science anew. Many technical

terms, however, have been explained, and their derivation given, in the Index.

To aid both in teaching and in learning, it will be observed that the subject has been broken up into numerous divisions and subdivisions, the headings of which have been so printed in diverse type as to catch the eye, and thus impress the memory.

To teach physiology efficiently, it will be a great assistance to the teacher to have the following appliances :

(1) *A human skeleton*, or the skeleton of any of the higher animals, such as a monkey, a dog, a cat, or a rabbit. Any of these may be obtained by applying to any well-known bookseller or surgical-instrument maker.

(2) *A good microscope*, capable of magnifying about 300 diameters. The one recommended by the author is No. IV. of Carl Reichert of Vienna, with objectives Nos. 3 and 7, at a cost of about £3, 10s. By means of this instrument, which ought to be provided by the authorities as part of the educational appliances of every school, a teacher can demonstrate the simpler tissues and fluids found in the body, and he will also be able to interest his pupils by showing infusoria, the humbler forms of plant life, &c., many of which may be found in the water of every stagnant pool by the roadside.

(3) *A set of diagrams.* These may be made by copying in Indian ink on a large scale, on cartridge paper, the woodcuts in this work. Photographs may also be easily taken of any of the illustrations, and lantern slides prepared. An occasional lantern demonstration, after the pupils have gone over the part of the subject to be illustrated, will be of great value.

(4) *Dissected preparations.* These may readily be procured by dissecting a rabbit. Skin the front part of the body, and also a limb ; clear off the loose tissue covering the muscles of the limb ; separate the muscles from each other ; expose the chief nerves and vessels in the limb ; open the chest and abdomen, so as to be able to point out the appearance and position of the chief organs ; and open the head, so as to expose the brain.

By such objective methods, after a little practice, the work of the teacher will become easy, and sound notions of anatomical structure and of physiological action will be taught.

I have to thank my assistant, Dr David Fraser Harris, for reading the proof-sheets.

JOHN G. M'KENDRICK.

University of Glasgow, *March* 1896.

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ELEMENTARY

HUMAN PHYSIOLOGY.

INTRODUCTORY.

When we examine the natural objects by which we are surrounded, we have little difficulty, as a rule, in distinguishing those which are dead from those which are living. Living things have certain properties not possessed by dead things. Thus, living things are produced, in the first instance, by living things like themselves, and they increase in size and grow by taking dead matter into themselves and making it alive ; there are constant exchanges taking place between them and the outer world—in other words, they eat, and breathe, and excrete, taking in matter and giving it out again ; they often move about apparently spontaneously ; they produce more or less heat by chemical changes in their tissues ; and, lastly, they usually pass through a kind of cycle in their life history. They are produced, they grow, they reach maturity, they decline, and they die. All living things do not manifest these properties to the same degree, and some of these properties may be so hidden as not to be readily observed. Still it is true that all living things—the lichen on the wall, the sea-weed, the flowering plant, the tree on the one hand, and the sea

anemone clinging to the rocks, the limpet, the fish, the snake, the bird, the rabbit, the ox, and man, on the other—show the same essential phenomena of life. The science that studies and describes these phenomena is called PHYSIOLOGY, an old term meaning a description of nature, and once embracing all physical phenomena, but now limited to those met with in living beings. The science consists of two great divisions—Animal Physiology and Vegetable Physiology. As the latter belongs to the province of the botanist, we have nothing directly to do with it in this work, which will be devoted to a short exposition of the chief facts relating to the mechanism of the animal body, and more especially to that of the body of man.

ANATOMY.—We may examine the body when it is dead by the art of dissection, as practised by the anatomist. He opens the cavities, separates one part from another, describes the position and relations of the various organs, and thus obtains knowledge of the general build or framework of the body. This constitutes the science of ANATOMY, and it is clear that, before we can hope to explain how the body works, we must know something of the structure of its parts. An engineer could never thoroughly understand the working of a steam-engine unless he had seen an engine built up bit by bit, wheel and piston and axle and bolts all mutually adjusted.

When the body of a man is looked at by the uninitiated, it appears to be so complex in structure as almost to baffle investigation; but, in the course of ages, men have succeeded by *dissection* in obtaining a tolerably accurate knowledge of the parts of which it is composed, so far as these can be seen by the naked eye. In more recent times, also, the *microscope* has been used for the examination of the minute structure of every organ and tissue; so that, while the department of microscopic anatomy is still far from having been completely worked out, every year is

adding to our knowledge. In describing the general anatomy of the body, therefore, it is convenient to divide it into (*a*) what may be seen with the naked eye; and (*b*) what can only be recognised with the microscope. In this Elementary Course the microscopical structure of the tissues and organs will be discussed very briefly.

Chemistry.—We obtain information regarding the nature of many things by submitting them to analysis, and resolving them into the chemical elements of which they are composed. Thus the chemist is able to tell us that a piece of chalk consists of carbonate of lime, which in turn may be decomposed into calcium, oxygen, and carbonic acid. In like manner, we may submit matter that was once alive, such as a bit of muscle or bone, to analysis, and ascertain the chemical compounds and the elements that exist in it. Such a proceeding, however, although it yields valuable information, does not teach much as to the chemical changes that occurred in matter when it was alive. Thus an analysis of muscle or flesh does not throw light on the chemical changes that occur in living muscle, nor does an analysis of the tissue of the lung tell us much about the changes in respiration. To understand the chemical changes in living matter which are intimately associated with the phenomena of life, we must analyse the substances that enter living matter, and the substances that issue from it, and then draw conclusions as to the changes that probably occur. For example, the true nature of respiration can be understood only by an analysis of the air before it enters the lungs in inspiration and after it has issued from the lungs in expiration, and by analysing the gases that exist in the blood flowing through these organs. We thus find that the essential change in breathing is that oxygen gas passes from the air into the blood, and that carbonic acid gas passes from the blood into the air. Thus, by studying (*a*) the chemical composition of the body and (*b*)

the chemical changes that occur in it, we are able to draw some conclusions as to the chemical phenomena or changes that appear to lie at the basis of all vitality.

THE BODY IN ACTION.—Having studied the analytical structure of the body, its chemical constitution, and the chemical changes that occur in it, we next proceed to view the body in action. We find it is composed of certain parts that are devoted to special uses. Such parts are termed ORGANS, and each organ performs one or more FUNCTIONS. By the function of an organ, we mean the part it has to play in the general mechanism. Thus the heart is a kind of pump for driving the blood through the vessels; the lungs are organs concerned in respiration; and the kidneys have as their function the elimination of water and other substances. Again, we find groups of organs associated in SYSTEMS or groups for special purposes, as the bones and muscles in locomotion; the heart, arteries, and veins in the circulation; and the stomach and intestines in digestion and absorption. All the organs and systems of organs are more or less under the control of the nervous system, which includes the organs known as the brain, spinal cord or marrow, the nerves, and the organs of sense.

It will thus be seen that there is a general and also a more special way of viewing the mechanism of the body. We shall discuss first those matters of general importance that relate to its anatomical structure, chemical constitution, and mode of action as a whole, and then we shall take up the function of the organs and systems of organs more in detail. The subject is thus divided into General and Special Physiology.

QUESTIONS.

What do you understand to be the distinctions between the sciences of Anatomy and Physiology?

Define the terms 'organ,' 'function,' and 'system.'

DIVISION I.—GENERAL PHYSIOLOGY.

CHAPTER I.

GENERAL VIEW OF THE ANATOMY OF THE BODY.

The body contains fluids and solids. The fluids are very abundant, existing not only in certain vessels or tubes fitted for their reception, but permeating the solid parts. Without these fluids the solid parts of the body would die. The solid parts consist chiefly of hard resisting parts termed the bones, of softer structures forming muscle or flesh, and of the various organs of the body, such as the brain, the lungs, or the heart.

The Locomotive Apparatus consists of two kinds of organs—the *bones* and the *muscles*. The *bones*, which are hard firm structures, form levers joined to each other by firm or movable *articulations* or *joints*, which often permit the bones to move on each other with great facility. The *muscles* constitute the chief part of what is usually called flesh, and they possess the property of contracting or shortening so as to move the bones to which their ends are attached. The bones may be called the passive, and the muscles the active, organs of locomotion.

A. THE PARTS OF THE SKELETON.

1. The Skeleton as a whole.—The whole of the bones in their natural position form the *skeleton*, which may be divided into the trunk and the limbs. The entire skeleton of an adult consists of two hundred bones, namely :

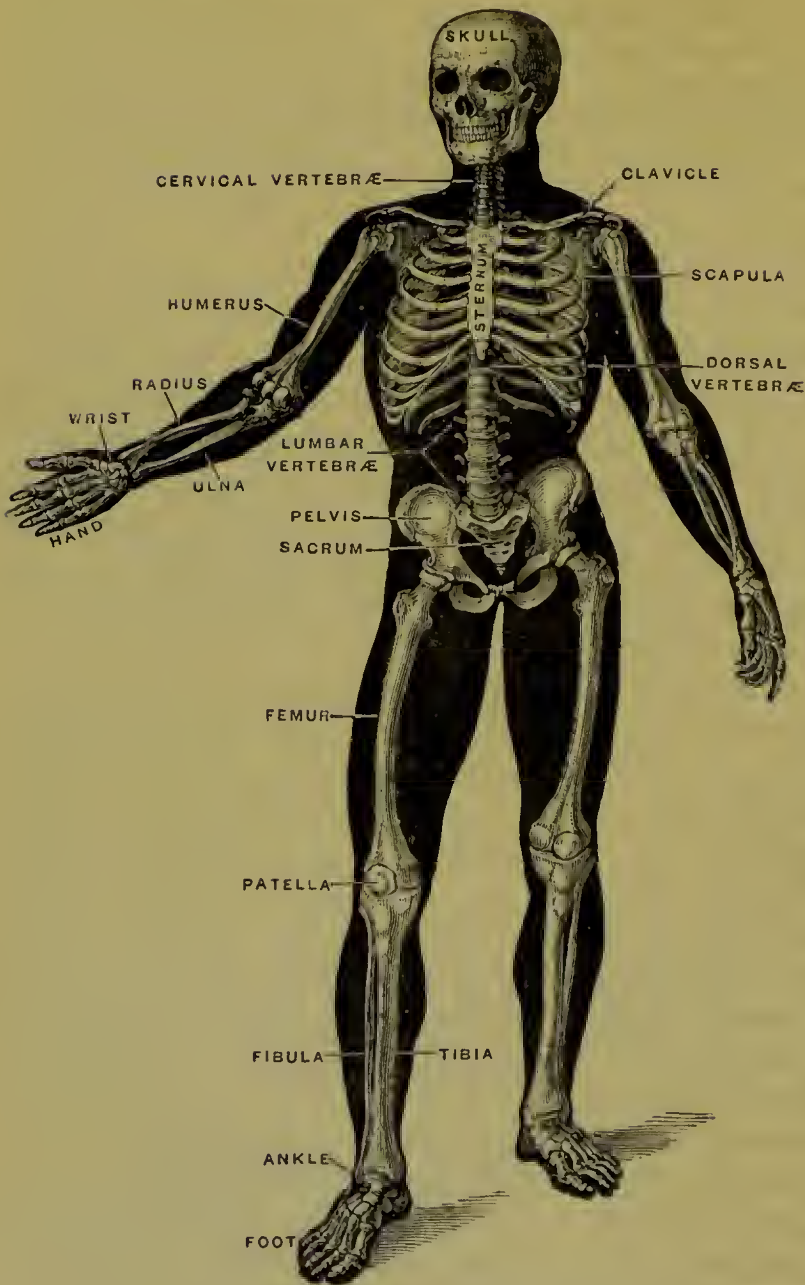


Fig. 1.—Human Skeleton viewed in front.

1.	The spine or vertebral column, including the sacrum and coccyx	26
2.	The cranium	8
3.	The face	14
4.	The hyoid bone, sternum, and ribs	26
5.	The upper extremities	64
6.	The lower extremities	62
		200

The trunk consists of, first, the spine or vertebral column (figs. 1, 2), a flexible stalk formed of a number of distinct bones articulated one below the other; second, the head, containing the brain and organs of sense, and consisting also of numerous bones; and third, the *thorax* or chest, composed of detached arches called the ribs, and which are connected in front, by *cartilage* or *gristle*, with a single bone, the *sternum*. The thorax contains the principal organs of respiration and circulation.

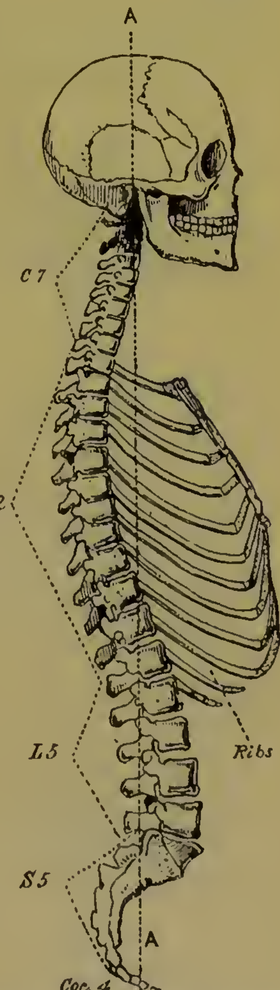


Fig. 2.—Axis of Spine, A, A: C, cervical (neck) vertebræ; D, dorsal (back) vertebræ; L, lumbar (loin) vertebræ; S, sacrum; Coc, coccyx.

The limbs, four in number, are termed *superior* and *inferior*. In man, the inferior limbs support the trunk, while the superior bear the hands, which serve as organs of prehension; but in the lower mammalia, as in the horse or dog, all four support the trunk. The superior limbs are divided into the shoulder, the arm, the forearm, and the hand. The inferior limbs comprise the haunch or pelvis, the thigh, the leg, and

the foot. In birds, the anterior or superior limbs constitute *wings*.

2. THE VERTEBRAL COLUMN.—This consists of twenty-four free bones called *vertebræ*, and of two bones at the lower extremity, each composed of several vertebræ, termed the *sacrum* and *coccyx*. Superiorly, it supports the skull; laterally, it has attached to it the ribs, through which it supports the weight of the upper limbs; and at its lower extremity it rests on the bones of the pelvis, which

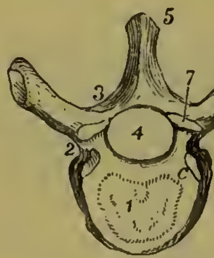


Fig. 3.—Dorsal Vertebra viewed from above:

1, body; 2, pedicels; 3, laminæ; 4, ring; 5, spinous process; 6, transverse process; 7, articular process for next vertebra; *c*, facet for head of rib; *d*, facet for tubercle of rib.

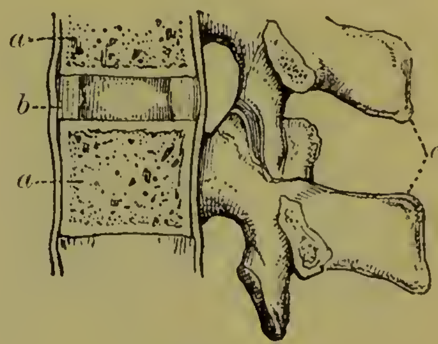


Fig. 4.

Section of Intervertebral Disc:

a, *a*, vertebræ; *b*, disc; *c*, spinous process.

transmit the weight of the body to the lower limbs. It also affords support and protection to the spinal marrow by enclosing it in a canal of bone. The bones of which it is composed are bound together by *ligaments* or bands, and by elastic discs of a fibrous and gristly substance called the *intervertebral* discs (fig. 4, *b*). There is thus secured great strength combined with flexibility. A certain amount of movement occurs between individual vertebræ, more especially in the cervical region.

3. GENERAL CHARACTERS OF A VERTEBRA.—Each vertebra has more or less the form of a ring, and presents a body (fig. 3, 1), which is placed anteriorly; a ring, 4—

containing the spinal cord and its membranes—which is formed by the body, 1; the pedicels, 2; the laminæ, 3; and the spinous process, 5. Attached to the ring we find the transverse processes, 6, placed one on each side, and the articular processes, also one on each side, 7, two superior and two inferior, for connection with the adjoining vertebræ.

4. CHARACTERS PECULIAR TO GROUPS OF VERTEBRÆ. —The vertebræ are divided into three groups—*cervical,* in

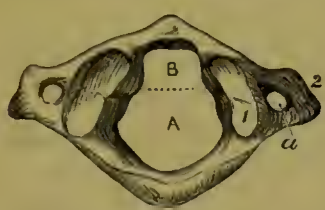


Fig. 5.—First Vertebra or Atlas: A, ring for spinal cord; B, ring for odontoid process of axis; dotted line indicates ligament; 1, articulation for occipital bone; 2, transverse process: *a*, canal for vertebral artery.

Fig. 6.—Second Vertebra or Axis: 1, odontoid process; 2, articulation for atlas; 3, canal for vertebral artery; 4, spinous process; 5, articulation for third cervical vertebra.

the neck; *dorsal,* in the back; and *lumbar,* in the loins. Of the first there are seven; of the second, twelve; and of the third, five (fig. 2). The first cervical, which supports the head, is called the *atlas* (fig. 5), and the second, the *axis.* The atlas has no body, and development shows that

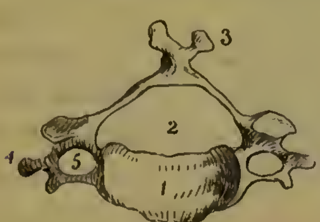


Fig. 7.—Cervical Vertebra: 1, body; 2, ring; 3, bifid spinous process; 4, transverse process; 5, canal for vertebral artery.

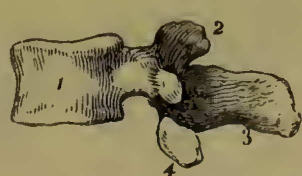


Fig. 8.—Lumbar Vertebra: 1, body; 2, transverse process; 3, spinous process; 4, articulation for next vertebra.

the process called the *odontoid process* of the axis (fig. 6, 1)

is in reality the body of the atlas connected with the body of the axis. The atlas, bearing the head, rotates round this process when the head is moved from side to side. The general characters of a cervical vertebra are seen in fig. 7, the two chief points being the notched spinous process, 3, and the canal in the transverse process for the vertebral artery, 5. The chief character by which a dorsal vertebra may be recognised is the presence on the body or transverse process of an articulating surface for the head or angle of the rib (see fig. 3, *c*, *d*). The lumbar vertebræ (fig. 8) have their bodies more massive than those of the dorsal, and the spinous processes are large, flat, and point directly backwards instead of downwards (fig. 2, L).

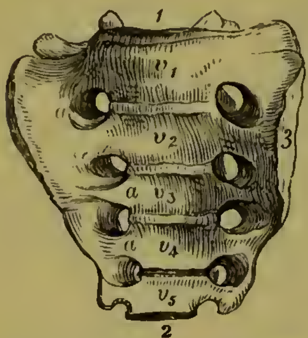


Fig. 9.—Front of Sacrum: 1, upper end; 2, lower end for coccyx; $v_1 - v_5$, vertebræ united; *a*, foramina or holes for sacral nerves; 3, articulation of pelvic bone.

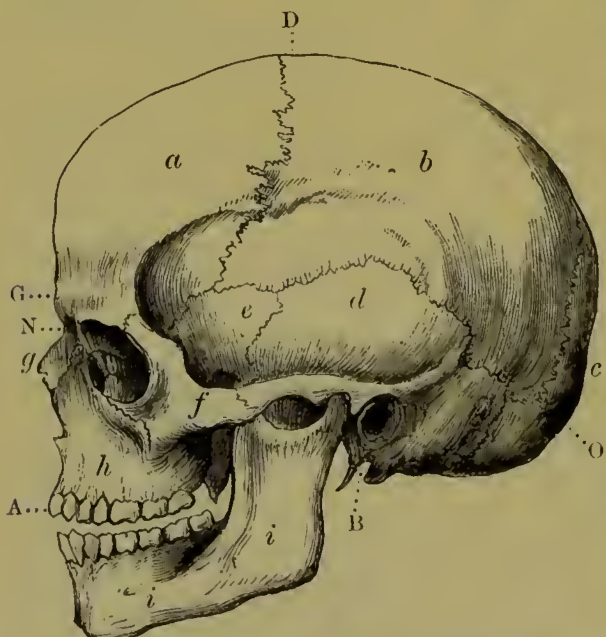


Fig. 10.—Side View of Human Skull: *a*, frontal bone; *b*, parietal bone; *c*, occipital bone; *d*, temporal bone (squamous portion); *e*, sphenoid bone; *f*, malar bone; *g*, nasal bone; *h*, superior maxillary or upper jaw-bone; *i*, inferior maxillary or lower jaw-bone. BD, height of cranium; GO, length of cranium; BN, basi-nasal length; BA, basi-alveolar length. (These measurements are supposed to be made in a straight line from point to point.)

5. The SACRUM (figs. 1, 2, and 9) is placed below the last lumbar vertebra, above the coccyx, and between the pelvic bones (fig. 1). It consists in early life of five vertebræ, which in the adult are united into one bone. The *coccyx*, at the lower extremity of the vertebral column, consists of four rudimentary vertebræ, which diminish in size from above downwards (figs. 2 and 18).

The average length of the vertebral column is about 28 inches, and it presents four curves in its course, the convexity being forwards in the neck and loins, and backwards in the back and pelvis (fig. 2).

6. The SKULL is supported on the vertebral column, and is formed of a number of bones, all of which, with the exception of the lower jaw, are firmly fixed together by surfaces termed *sutures*. It is divided into two portions—the *cranium* and the *face*. The cranium protects the brain; the face surrounds the nose and mouth, and contains several of the organs of sense. The cranium (fig. 10) is composed of eight bones—namely, the occipital, *c*; the two parietal, *b*; the frontal, *a*; the two temporal, *d*; the sphenoid, *e*; and the ethmoid. The sphenoid forms part of the base of the skull (a little in front of 5, fig. 11), and the

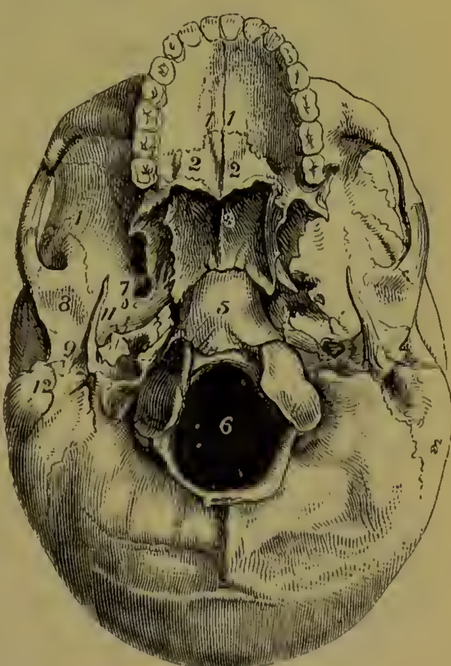


Fig. 11.—Base of Skull:
1, 1, superior maxillaries; 2, 2, palate; 3, vomer; 4, wing of sphenoid; 5, basilar process of occipital; 6, foramen magnum; 7, foramen ovale; 8, temporal; 9, 11, styloid process of temporal; 12, mastoid process.

ethmoid is found (immediately above and behind N in fig. 10) between the orbital plates of the frontal bone, and enters into the formation of the orbits and the nasal cavities. The *face* is composed of fourteen bones, of which twelve are in pairs, the two superior maxillary (fig. 10, *h*, and fig. 11, 1, 1), the malar (fig. 10, *f*), the nasal (fig. 10, *g*), the palate (fig. 11, 2, 2), the lachrymal (a little to the right of *g* in the orbit, fig. 10), and the inferior turbinated in the nose; and two single, namely, the vomer, a bone forming a partition between the two nostrils (fig. 11, 3), and the inferior maxillary (fig. 10, *i*).

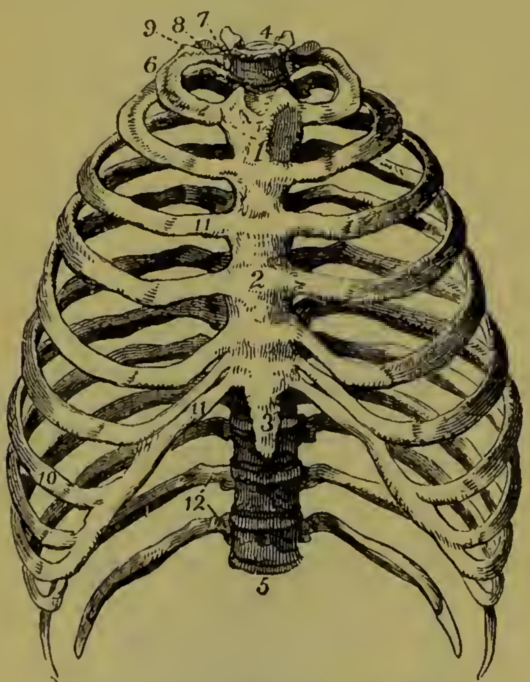


Fig. 12.—The Ribs, *in situ:*

1 and 2 are the upper and the middle parts of the sternum or breast-bone; 3, its ensiform cartilage; 4, the first dorsal, and 5 the last (or twelfth) dorsal vertebra; 6, the first rib; 7, its head; 8, its neck, resting against the transverse process of the first dorsal vertebra; 9, its tubercle; 10, the seventh or last true rib; 11, the costal cartilages of the true ribs; 12, the last two false ribs or floating ribs.

7. The Cranial Cavity is seen on sawing off the roof of the skull. The walls consist of two layers of compact tissue, the *outer* and *inner tables*, and between these a cellular structure known as the *diploe*. The upper part of the cranial cavity forms an arch, and the lower is divided into three parts having different levels, called the anterior, the middle, and the posterior fossæ, in which the anterior and middle lobes of the cerebrum and the cerebellum rest. The base is perforated by numerous openings for the passage of nerves

and blood-vessels. The most notable of these openings is the *foramen magnum* (fig. 11, 6), for the passage of the spinal marrow and of certain blood-vessels.

8. The THORAX, or chest, consists of the dorsal vertebræ, the *sternum* or breast-bone (fig. 12), the *ribs*, and the *cartilages* connecting these with the sternum, known as the costal cartilages. The sternum, 1-3, is situated in the median line at the fore-part of the thorax, and is connected with the rest of the trunk by the costal cartilages of the seven highest pairs of ribs, 11, 11. The ribs are twelve in number on each side. They are long slender curved bones which extend forwards from the spine, some of them joining the breast-bone or sternum. The seven upper ribs, which join the sternum by cartilages, are termed the 'true' ribs; while the lower five, which do not join the sternum, are termed the 'false' ribs (see fig. 12, 12). Each rib has a double attachment to the backbone posteriorly; by its *head*, which unites with the body of the vertebræ (fig. 3, *c*), and by a rounded prominence, called the *tubercle*, with the transverse process of the vertebra (fig. 3, *d*). The ligaments binding the ribs to the vertebral bones are seen in fig. 13. The costal cartilages

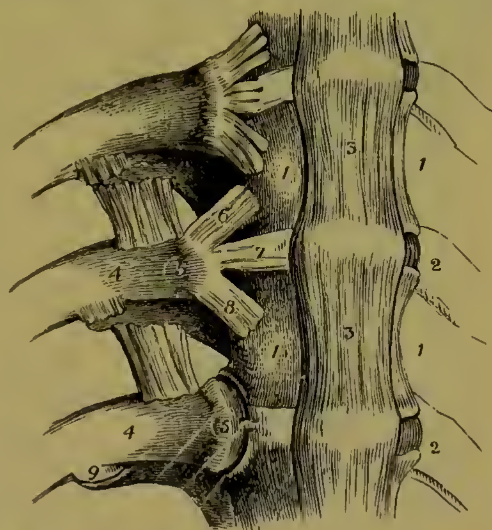


Fig. 13.—A Front View of the Articulations of the Ribs with the Spinal Column:
1, 1, dorsal vertebræ; 2, 2, intervertebral cartilages; 3, 3, anterior common ligament; 4, neck, and 5, head of rib; 6, 7, 8, flat bundles of ligamentous fibres (removed in the lowest rib shown in the figure); 9, articulation between the tubercle of the ribs and the transverse vertebral process.

are continuations of the ribs. They give elasticity to the framework of the thorax. In advanced life they become impregnated with earthy matter, partially lose their elasticity, and thus diminish the force and depth of respiration.

9. THE BONES OF THE UPPER EXTREMITY.—The upper extremity consists of the shoulder, the arm, the fore-arm, and the hand. The bones of the shoulder are the scapula (fig. 1) or shoulder-blade, and clavicle or collar-bone (fig. 1); in the arm, is the humerus (fig. 1); in the fore-arm, are the radius and ulna; and in the hand, three groups of bones—the carpus, metacarpus, and digital phalanges. The *scapula* (fig. 14), placed on the upper and back part of the thorax, is attached directly to the trunk only by the clavicle, and from it the humerus is suspended. The *clavicle* is a long cylindrical bone placed on each side of the neck, and connecting the sternum with 12 (fig. 14), the acromion process of the scapula (fig. 15, *c*). The *humerus* (fig. 15, *h*) is an imperfectly cylindrical bone, extending from the shoulder to the elbow-joint. In the figure it is seen as it is placed when the arm is hanging down and the palm turned forwards. It consists of a head which articulates with the scapula at 6 (fig. 14), of a shaft, and of a lower end, which supports the radius

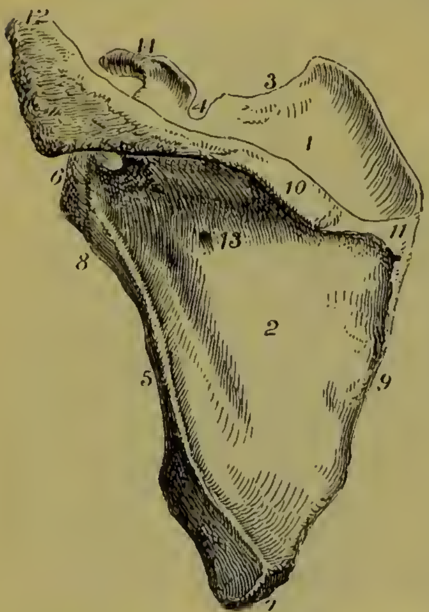


Fig. 14.—Posterior View of the Left Scapula:

The parts designated by the figures 1, 2, 4, 6, 8, 10, 11, 12, are sufficiently described in the text; 3 is the superior border; 5, the external or axillary border; 7, the inferior angle; 9, the internal or vertebral border; 12, the acromion process; 13, one of the holes for the passage of an artery into the bone; 14, the coracoid process.

and ulna. The two bones of the fore-arm are seen in fig. 15. They consist of the *radius*, *r*, which is the external of the two bones of the fore-arm, and the *ulna*, *u*, which is the internal. The radius articulates above with the humerus, and below with two of the bones of the carpus, or wrist. The ulna articulates with the humerus and the radius, but is not directly connected with the carpal bones, a thin, fibro-cartilaginous disc being interposed between its lower end and the

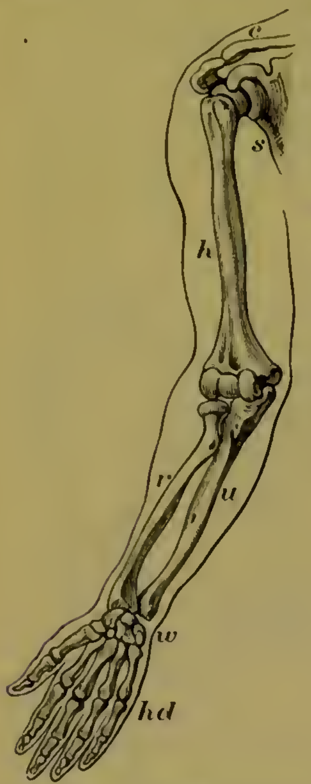


Fig. 15.—Bones of the Human Arm:

h, humerus; *r*, radius; *u*, ulna; *w*, wrist-joint; *hd*, hand; *s*, scapula; *c*, clavicle or collar-bone.

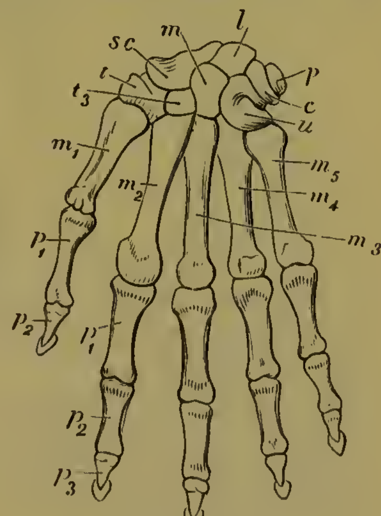


Fig. 16.—Posterior Aspect of Left Hand.

For description, see text.

cuneiform bone (fig. 16, *c*). When the arm and hand hang downwards, the palm being directed forwards, the position is called *supination*; but when in the same position the back of the hand is directed forwards, the position is called *pronation*. These movements are effected by the rotation of the radius on the lower end of the humerus. The *carpus*, or wrist, consists of eight short

bones, arranged in two rows. Enumerated from the radial or thumb side, they are (fig. 16), in the first row, the scaphoid, *sc*; the semilunar, *l*; the cuneiform, *c*; and pisiform, *p*; and in the second row, in the same order, the trapezium, *t*; the trapezoid, t_3; the os magnum, *m*; and the unciform, *u*. The *metacarpus*, forming the palm, consists of five shafted bones which support the fingers, m_1, m_2, m_3, m_4, and m_5. The *digital phalanges* are fourteen in number, three for each finger, except the thumb, which

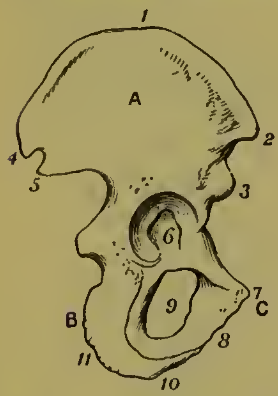


Fig. 17.—Outer Aspect of Right Os Innominatum or Iliac Bone:

A, ilium; B, ischium; C, pubis; 1, crest of ilium; 2, anterior superior spine; 3, anterior inferior spine; 4, posterior superior spine; 5, posterior inferior spine; 6, acetabulum; 7, symphysis pubis; 8, descending ramus of pubis; 9, obturator foramen; 10, ascending ramus of ischium; 11, tuberosity of ischium.

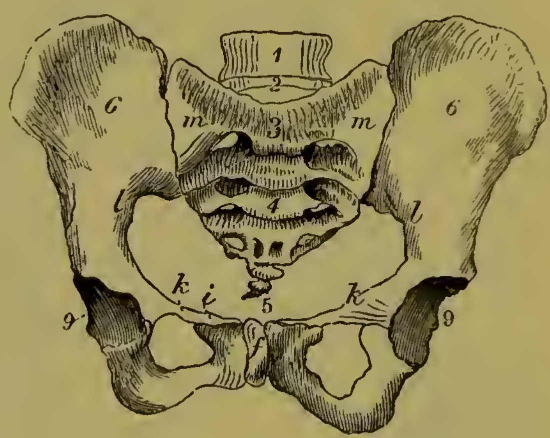


Fig. 18.—Pelvis:

1, lower lumbar vertebræ; 2, 3, 4, sacrum; 6, 6, innominate bones; 5, coccyx; 9, acetabula; *f*, symphysis pubis; *l i l*, *k k*, brim of pelvis.

has only two. In each instance, the proximal phalanx, p_1, is longer than the second, p_2, and the second longer than the third, p_3.

10. The Bones of the Lower Extremity.—The lower limb is divided into the haunch or hip, the thigh, the leg, and the foot. The haunch-bone on each side, with the sacrum wedged in between, and bearing the coccyx

at its lower extremity, forms the *pelvis*, which transmits the weight of the body to the lower limb. It is usually called the *innominate* bone, or *os coxæ* (fig. 17). The *pelvis*, or basin (fig. 18), contains the urinary and generative organs and the lower end of the alimentary canal. Its upper opening is termed the *inlet*, and its lower the *outlet* of the pelvis. In the erect position (fig. 1), the pelvis is so inclined that the plane of the brim forms an angle of from 60° to 65° with the horizontal. The line of pressure of the weight of the body on the sacrum is downwards and forwards towards the junction of the two innominate bones termed the symphysis pubis (fig. 18, *f*), and the pressure is communicated to the heads of the thigh-bones, which are lodged in deep depressions termed the acetabula (fig. 17, 6; fig. 18, 9; and fig. 1). The form and size of the pelvis differ in the two sexes, as it is broader, more expanded, and shallower in the female than in the male.

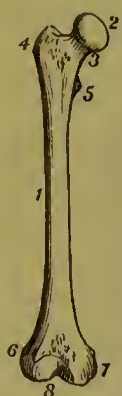


Fig. 19.—Front View of the Right Femur: 1, shaft; 2, head; 3, neck; 4, greater, and 5, lesser trochanters; 6, external, and 7, internal tuberosity; 8, articulation for tibia and patella.

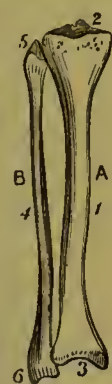


Fig. 20.—Front View of Right A, Tibia, and B, Fibula: A—1, shaft; 2, articulation with femur; 3, articulation with astragalus. B—4, shaft; 5, head; 6, lower end. Observe fork-shaped cavity at lower end for astragalus.

The *femur*, or thigh-bone (fig. 19), the largest bone of the skeleton, articulates, 2, above with the acetabulum of the os innominatum (figs. 17, 6, and 18, 9). In the erect position it inclines inwards and slightly backwards, and it is divisible into a shaft, having at one end a head, 2, attached to it by a neck, 3, and bearing two rough promi-

nences for the attachment of muscles, called respectively the great, 4, and the small, 5, *trochanters;* and at the other, or inferior extremity, a broad, irregularly shaped surface called the external, 6, and internal, 7, *condyles*, for articulation with the tibia. In the female, from the greater breadth of the pelvis, the thigh-bones converge more towards their lower extremity than in the male.

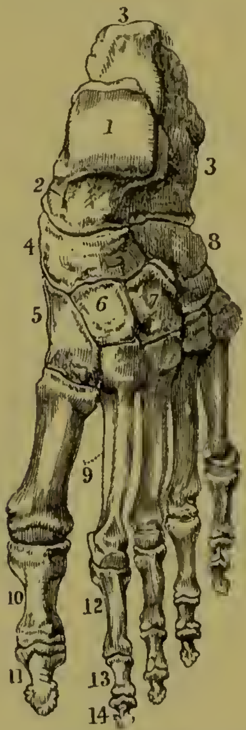


Fig. 21.—Upper View of Left Foot: 1, the astragalus, its upper articular surface; 2, its anterior extremity, which articulates with 4, the scaphoid bone; 3, the os calcis, or heel-bone; 4, the scaphoid bone; 5, the internal cuneiform bone; 6, the middle cuneiform bone; 7, the external cuneiform bone; 8, the cuboid bone; 9, the metatarsal bones of the first and second toes; 10, 11, the first and second phalanges of the great toe; 12, 13, 14, the first, second, and third phalanges of the second toe.

The *patella* or knee-pan (fig. 1) is situated in front of the knee-joint, and may be regarded as a mass of bone developed in the tendon or sinew belonging to the great muscle in front of the thigh by which the leg is extended on the thigh.

The bones of the leg are two in number, the inner termed the *tibia* or shin-bone (fig. 1, and fig. 20, A), and the outer, the *fibula*, or clasp-bone (fig. 20, B). The tibia alone communicates the weight of the trunk to the foot. It articulates inferiorly with one of the bones of the ankle termed the *astragalus* (fig. 21, 1). The fibula is much more slender than the tibia.

The *foot* is divided into the *tarsus*, the *metatarsus*, and the *phalanges*. The tarsus consists of seven bones—namely (fig. 21), the os calcis, or heel-bone, 3; the astragalus, which receives the weight of the body from the leg, 1; the cuboid, so named from its shape, on the outer side of the foot, 8; the scaphoid or navicular bone, 4, and the three cuneiform or wedge-shaped bones intervening between the scaphoid and the metatarsals, 5, 6, 7; the metatarsal bones, 9, are five in number, and they bear the phalanges of the toes, 10, 11, 12, 13, 14.

The foot as a whole is admirably adapted for receiving the weight of the body, and for affording stability. It is arched from behind forwards, the posterior support of the arch being formed by the heel, and the anterior by the

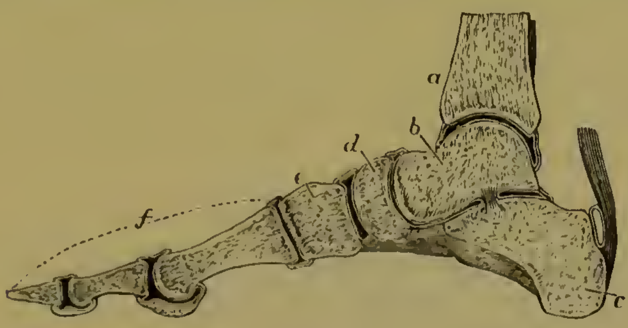


Fig. 22.

Section through the lower end of the tibia *a*, and through the astragalus *b*, the heel-bone *c*, the scaphoid bone *d*, the internal cuneiform bone *e*, and the bones of the great toe *f*.

balls of the toes—indeed, the arch may be regarded as having a single pier behind and a double in front (fig. 22).

11. Adaptation of the Skeleton of Man to the erect position.—The skull of man is nearly balanced on the vertebral column (fig. 2), whereas in the lower animals it is suspended, as it were, from the extremity of the column, and is sustained by an elastic ligament (*ligamentum nuchæ*), which runs from the spinous processes of the vertebræ to a protuberance on the occipital bone. The body is balanced

on one or both of the lower limbs, which can be extended in a straight line at the knee-joint. The foot of man alone possesses an arched instep, and the great toe is not intended for grasping, as in the monkeys, but for supporting weight and giving elasticity to the step. The great length of the femur enables the body to be balanced as in crouching, and the great breadth of the pelvis enables the equilibrium to be maintained even during considerable lateral movements. The spinal column, by becoming broader inferiorly, is fitted to sustain weight, and by means of its curvatures elasticity and strength are secured, while a wide range of movement is permitted. In man, the articular facet on the scapula for the head of the humerus looks outwards, so as to allow a free play of the upper extremity at the shoulder-joint. Mobility, lightness, and delicacy of movement are permitted by the structure of the upper limb, as contrasted with strength and firmness in the lower, as may be seen on comparing the shoulder, elbow, and wrist, with the hip, knee, and ankle.

THE JOINTS.

12. General Description.—A joint is the union of any two segments of the skeleton through the intervention of a structure or structures of a different nature. *Bone* forms the fundamental part of all joints; strong bands or *ligaments* hold the bones firmly together; and in joints in which there is free movement, we find the ends of the bones covered by *cartilage* or gristle, and the joint lined by a smooth membrane termed a *synovial* membrane. This membrane secretes a thin, watery fluid, *synovia*, which lubricates the surfaces and diminishes friction. Joints are divided into three classes: (1) those in which the parts are continuous and there is no synovial membrane between the bones, as seen in the construction of the skull (fig. 10); (2) those in which there is an intervening substance between the bones in the form of a disc or cushion of fibro-cartilaginous substance, allowing a certain degree of mobility, as in the articulations between the bodies of

the vertebræ (fig. 4); and (3) those in which we find a complete joint having the ends of the bone covered with cartilage, the surface of which is lubricated by the synovial fluid secreted from the delicate synovial membrane which lines the fibrous coverings and all parts of the articulating cavity except the cartilage (figs. 15, 22, and 23). In movable joints the degree and nature of the movement are very various, but four varieties may be noted: (1) *Shifting joints*, where there is merely a gliding motion between the ends of the bones, as seen in the articulations between the bones of the carpus or tarsus. In these cases the surfaces are plane, or one is slightly concave while the other is slightly convex; and the motion is limited in extent and direction by the ligaments of the joint, or by some projecting point of one of the bones. (2) *Ball and socket joints*, where one bone presents a cup-like depression, while the termination of the other assumes a hemispherical or more or less globular shape, as in the hip-joint. In such a joint, the ball is kept in apposition with the socket by means of what is termed a capsular ligament (fig. 23, 14, 14), which is an expansion of ligamentous structure, attached by its extremities around the margins of the articular surfaces composing the joint, and forming a complete investment of it, but not so tight as to restrict its movements too much. Fig. 23 shews the hip-joint, where in addition we find a strong round fibrous cord termed the *round ligament*, 12, passing from a depression in the head of the femur to the margin of the acetabulum or articular cavity on the *os innominatum*, 11. In such a joint the pressure of the air on the external surface assists in maintaining apposition, for when a hole is bored through the floor of the acetabulum so as to admit air into its cavity, the head of the thigh-bone at once falls away as far as the ligaments will allow

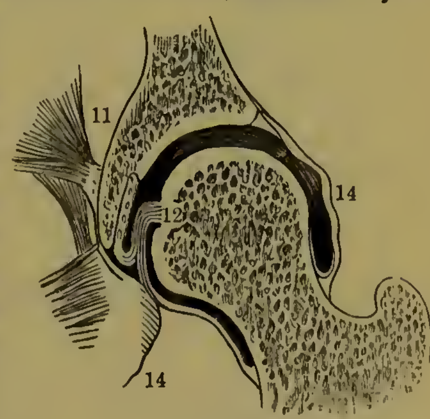


Fig. 23.
Section through the Left Hip-joint.
For description see text.

it. (3) *Hinge joints*, in which the contiguous surfaces are marked by elevations and depressions, which exactly fit into each other, so as to restrict motion to one direction. The elbow and ankle joints are the best examples of this variety. The knee-joint is not a pure hinge joint, because it admits of a certain amount of rotation when the leg is slightly bent at the knee. (4) *Rotatory joints*, which admit only of rotatory motion. A pivot and ring are the essential parts of this joint, the ring being generally composed partly of bone and partly of ligament. The best example of this articulation is that between the atlas (fig. 5, B) and the odontoid or tooth-like process of the axis (fig. 6, 1).

Questions.

1. Enumerate the bones found in the skeleton.
3, 4. Describe a vertebra, and point out the peculiarities which distinguish a cervical from a dorsal vertebra.
6. Enumerate the bones entering into the formation of the skull.
7. What is the structure of one of the flat bones of the skull?
8. Describe how the ribs are attached to the back-bone and to the breast-bone.
9. Describe the bones entering into the formation of the elbow-joint. Enumerate the bones of the carpus.
10. Describe the general structure of the pelvis. What bones form the ankle-joint?
11. Show how the skeleton of man is adapted to the erect position.
12. Enumerate the different kinds of joints. Describe the hip-joint, as regards bones, ligaments, and movements.

B. THE SOFT PARTS OF THE BODY.

a. THE MUSCLES.

13. Clothing the framework formed by the bones of the skeleton, we find what is usually described as the flesh. When this is carefully dissected, it is found to consist mainly of certain organs termed the *muscles*. If we remove the skin from one of the extremities, say the arm, we find underneath it a strong fibrous covering termed the *fascia*, which sends sheaths between the muscles, so that each muscle is completely surrounded by it. The fascia is

usually divided into *superficial* and *deep*, the first being a layer of loose tissue placed immediately below the skin all over the body, and the latter is that stronger layer of fibrous tissue which lies close to the muscles, and invests them in the manner already indicated. On carefully removing the fascia, the muscles may be displayed, as seen in fig. 24, which represents the muscles of the human arm. If we examine a single muscle, as the biceps, *o*, it is found to be connected with the bones at its two extremities, and to present a fleshy mass between the two attachments, which are more tendinous or sinewy in character. Each muscle may be regarded as an organ having a special function to perform. When irritated during life, it possesses the property of contracting or shortening itself, and consequently of bringing its two attachments nearer to each other. If there be a joint between the two attachments, the bones of this joint are moved upon each other in a definite direction, and thus locomotion is effected (fig. 25).

Fig. 24.—Muscles of the Human Arm:

abc, deltoid muscle; *d*, coraco-brachialis muscle; *r*, *r*, triceps; *e*, *i*, extensors of wrist and long supinator of the hand; *k*, *m*, flexor of fingers and radial and ulnar sides of the wrist, and *l*, palm of the hand, or palmaris longus; *p*, palmaris brevis; *q*, palmar fascia; *o*, biceps.

14. The various muscles found in the body may be conveniently classified according to their mechanical action as follows: *Flexors*, or those which bend the limbs, such as the biceps (fig. 24, *o*); *extensors*, which straighten the limbs, such as the triceps, the fleshy mass on the back of the upper arm, *r*, *r*;

adductors, and *abductors*, which produce angular movement to and from the median plane of the body such as the muscles

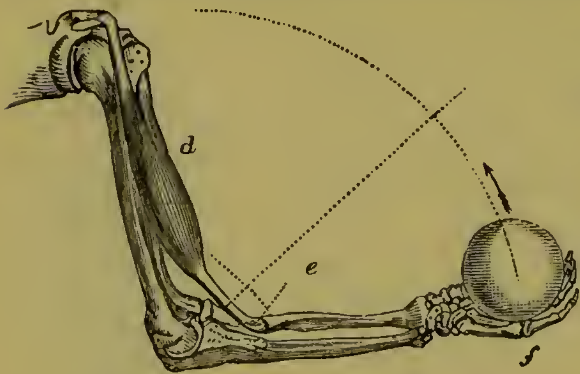


Fig. 25.

Shows a weight supported on the palm of the hand, *f*, and raised in the direction of the arrow by the contraction of the biceps muscle, *d*. Observe the attachment of lower end of biceps at *e*, and the position of the elbow joint.

which enable us to move the thigh outwards and inwards from the hip ; and *rotators*, which effect movement of a bone round its axis without any great change of situation. As an example of rotation, take those of pronation and supination already referred to (p. 21). In pronation (*pronus*, with the

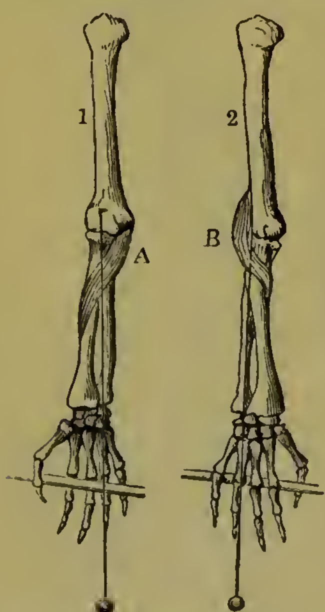


Fig. 26.

1, The Upper Limb, with the forearm and hand in the state of supination : A, pronator muscle. 2, The same in a state of pronation : B, the supinator muscle. In both figures, a plumb-line from the outer condyle of the humerus is found to traverse the lower end of the ulna and the ring-finger.

face downwards), we turn the palm of the hand downwards as in picking anything from the table ; in supination (*supinus*, with the face upwards), we turn the palm upwards, as for the purpose of receiving anything that may be placed in it. These

Fig. 27.—Muscles of Human Body. Deep muscles shown on left side: *a*, flexors of hand and fingers; *b*, extensors of hand and fingers; *c*, biceps; *d*, triceps; *e*, deltoid; *f*, pectoralis major; *g*, serratus magnus; *h*, gluteus; *i*, rectus; *k*, extensors of leg; *l*, sartorius; *m*, gastrocnemius; *n*, tendo Achilles; *o*, *o*, ligament.

movements are effected by certain muscles causing the radius, which bears the hand, to rotate round a longitudinal axis (see fig. 26). One of the three muscles (A) passes from a projecting process on the inner side of the humerus, at its lower end, to the outer edge of the middle of the radius. When it contracts, the radius rotates and rolls over in front of the ulna (as in 2), and it is called a *pronator* muscle. A second muscle (B) passes from a projecting process on the outer side of the humerus to the inner side of the radius near its upper part. It runs therefore in an opposite direction to the former muscle, and produces an opposite effect, rolling the radius and hand back into the position of supination. Hence it is called a *supinator*. The third muscle, the biceps (fig. 24, *o*), not only bends the elbow, but from the mode in which its tendon is inserted, it also rotates the radius so as to supinate the hand, as when we turn a screw or draw a cork. Supination can only be performed to its full extent by man ; monkeys can partially effect the movement, and in most of the lower animals the part corresponding anatomically to the hand is constantly in a state of pronation. Sometimes the combined action of various groups of muscles may take place, as when we swing the arm round and round in the shoulder-joint. This is termed *circumduction*, when the limb is made to describe a cone by rotation round an imaginary axis, the apex of the cone being in the joint.

A general view of many of the muscles of the human body is given in fig. 27.

b. THE CONNECTIVE TISSUES.

15. This term is applied to various kinds of tissue that bind together and support the other tissues of the body. They vary very much in appearance in the fully formed condition, but when we study their origin they are found to spring from a tissue that has always the same general characters, some of which will be afterwards described. Thus we find that bone, cartilage, the tissue that forms tendons or sinews, the tissue forming the ligaments that bind the bones together, the tissue that forms the fasciæ and sheaths of muscles already alluded to, the tissue con-

taining the fat below the skin, and the tissue consisting of fine fibres that forms a supporting structure in nearly all the organs of the body, must all be regarded as belonging to the connective tissue group. The soft parts consist largely of this kind of tissue.

c.

OTHER SOFT TISSUES.

16. Distributed among the muscles and the connective tissues already noticed, we find *blood-vessels*, or tubes for the distribution of blood, consisting of arteries, capillaries, and veins. We also find numerous *nerves*. These soft tissues will be fully described when we consider the circulation of the blood, nutrition, and the functions of the nervous system (fig. 28).

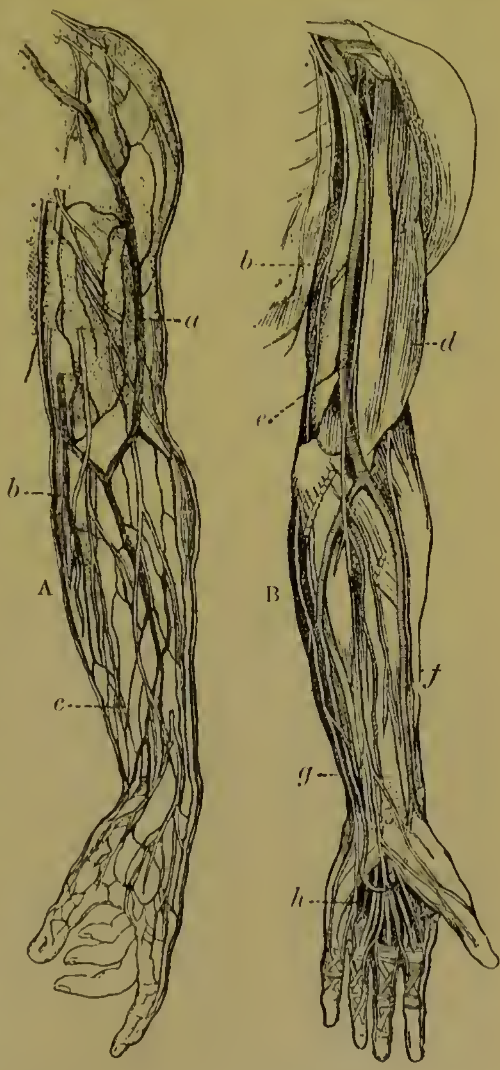


Fig. 28.—A, superficial, and B, deep, dissected view of Left Arm :

a, veins; *b*, *b*, nerves; *c*, fascia or membrane; *d*, biceps; *e*, brachial artery; *f*, radial artery; *g*, ulnar artery; *h*, arteries in palm.

d. THE SKIN.

17. Clothing the surface of the body, we find the *skin*. This organ consists of certain layers,

to be afterwards described, and it is richly supplied with minute blood-vessels and with nerves. The skin protects the parts situated beneath it; it contains the organs by which we appreciate contact or touch; it contains also certain glands that secrete the *sweat* and the oily substance called *sebaceous matter*, and it has important functions in connection with the regulation of the temperature of the body. At certain places, such as the openings of the mouth and nostrils, the anus, and the opening of the urinary passages, the skin becomes continuous with the membrane that lines the alimentary canal, the respiratory and other passages.

e. MUCOUS MEMBRANES.

18. These are thin membranes lining passages and cavities that communicate with the exterior. They are covered or protected by a somewhat viscid or sticky fluid termed *mucus.* Such a membrane always consists of a layer of connective tissue covered with one or more layers of cells known as *epithelial cells*, and thus it follows that no foreign substance can pass into the tissues of the body, say from the cavity of the stomach or bowels, without passing through such a layer of epithelium. The chief mucous membranes are the *gastro-pulmonary* and the *genito-urinary.* The *gastro-pulmonary* lines the alimentary canal from the mouth to the anus, and it also extends into the air passages and lungs, lining the windpipe, bronchial tubes, and air-cells in the lung, where the respiratory exchanges between the blood and the air take place. The respiratory mucous membrane passes also from the interior of the nose into the tear ducts or lachrymal passages, and it covers the front of the eyeballs and lines the eyelids under the name of the *conjunctiva.* From the back of the throat the membrane passes into the *Eustachian tube*, a canal communicating with the middle ear or tympanum. Lastly,

the gastric mucous membrane lines the ducts of all the secreting glands that open into the alimentary canal, such as the salivary glands, the pancreas, and the liver.

19. The *genito-urinary* mucous membrane passes from the orifice of the urethra, or opening of the urinary passage, through the urinary tract to the bladder, and from thence through the ureters to the kidneys, and it also lines the generative passages of the female. The minute structure of mucous membranes will be further described.

Questions.

13, 16. What tissues form the so-called *flesh* of a limb?
14. Give an example of each of the different kinds of muscles. Describe the movements of pronation and supination.
15. What do you understand by connective tissue?
17. What glands occur in the skin?
18. What is a mucous membrane? Describe the general distribution of the gastro-pulmonary mucous membrane.

C. THE INTERNAL ORGANS.

20. The body without the limbs is divided into the trunk and head. These are cavities containing certain internal organs. The cavity of the head contains the brain. The trunk is subdivided into the thoracic, abdominal, and pelvic cavities. The thoracic cavity, usually called the chest, contains the trachea or windpipe, the lungs, the heart, the œsophagus or gullet, and the great blood-vessels entering into and issuing from the heart (fig. 29). A membranous-muscular partition, the diaphragm (O, fig. 29), separates the thoracic cavity from the abdominal cavity. The abdominal cavity contains the stomach, liver, gall-bladder, spleen, pancreas, kidneys, and small and large intestines, &c. (fig. 29). The pelvic cavity contains the bladder, rectum or lower bowel, and the generative organs. Another mode of gaining a conception of the cavities of the body is to suppose it to be divided by a vertical

plane passing through the bodies of the vertebræ from the base of the skull downwards (fig. 30, A). The body is thus divided into anterior and posterior cavities. The posterior cavity in the head contains the brain, while the anterior is represented by the cavities of the mouth and

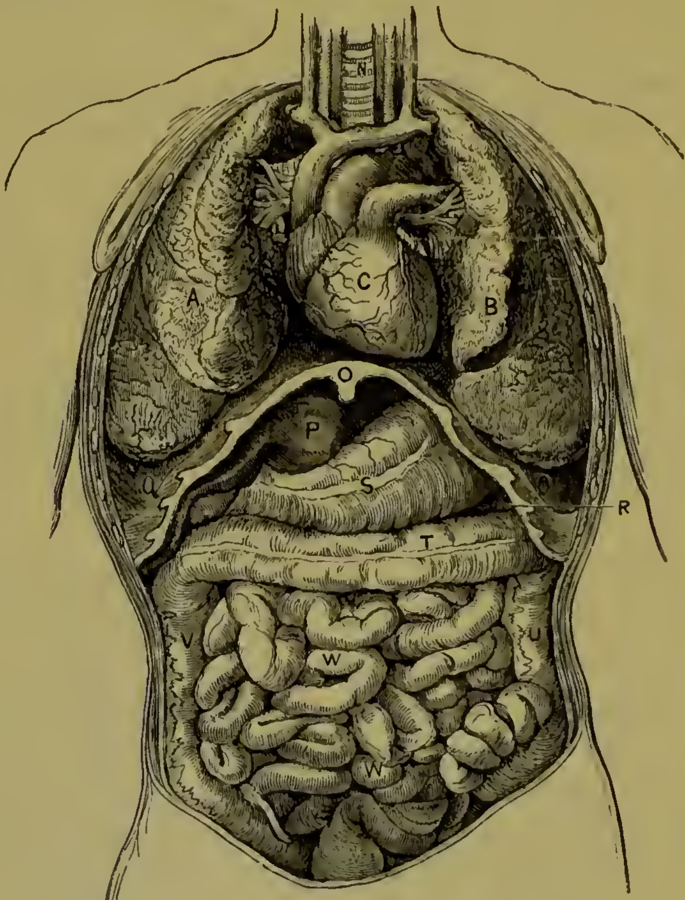


Fig. 29.—Contents of the Chest and Abdomen :
O, diaphragm ; C, heart ; A, B, lungs ; N, windpipe ; P, liver ; R, spleen ; S, stomach ; W, W, small intestine ; T, U, V, large intestine.

nose. In the trunk, the posterior cavity is occupied by the spinal cord, while the anterior consists of the cavities of the thorax, abdomen, and pelvis. With the exception of the cavities of the mouth and nose, which are the openings of the alimentary and respiratory

systems respectively, the cavities are shut off from direct communication with the exterior, and each is lined by a thin *serous* membrane (so called because it secretes a watery fluid like that found after blood has clotted), which is reflected over the surfaces of most of the organs contained in the cavity. The serous membrane consists of a thin layer of connective tissue covered by a single layer of flattened cells. A small amount of a watery fluid is secreted or formed by these cells, thus moistening the surface and diminishing friction when the inner surface of the wall of the trunk touches or rubs against the outer surface of the organs contained in the cavity.

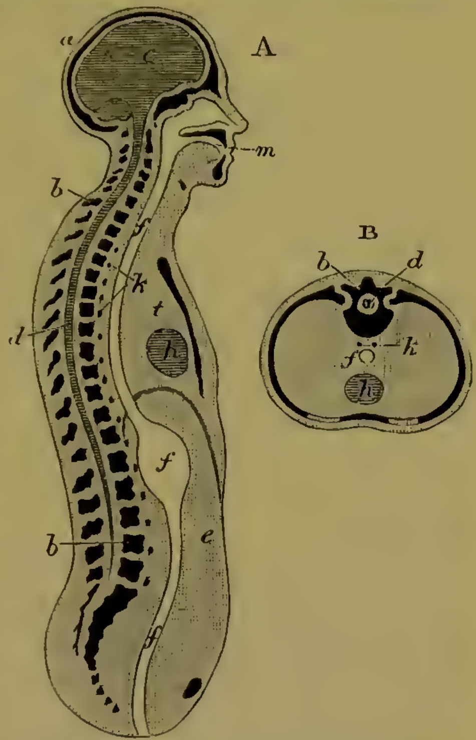


Fig. 30.—(A) Vertical and (B) Transverse Sections of the Human Body: *a*, skull; *b*, *b*, vertebræ; *c*, brain; *d*, spinal cord; *c*, abdomen; *f*, *f*, *f*, digestive system; *h*, heart; *k*, sympathetic nervous system; *m*, mouth; *t*, chest.

The *cavities* of the body contain important organs, the general position of which and their relation to other parts should be known before we proceed to consider their functions.

QUESTIONS.

20. Enumerate the organs found in the thorax. Enumerate the organs found in the abdomen. Make a drawing showing what may be seen in a transverse section of the body.

I. THE CENTRAL NERVOUS ORGANS.

21. The central nervous system is sometimes called the *cerebro-spinal axis*, and is contained partly within the cavity of the cranium, and partly within the canal formed by the rings of the vertebræ called the vertebral canal (see figs. 3 and 30). It is divided into the large mass placed in the cranium called the *brain*, and the *spinal cord* within the vertebral canal. Both the brain and spinal cord consist of a right and left half, which are symmetrical and very similar in structure to each other, each half being connected with the other by bands of nervous matter, so as to form one complete organ. The brain and cord are protected by the bony walls of the skull and vertebral column, and they are surrounded by three membranes which give additional protection and aid in the nutrition of the organs.

22. The *spinal cord* or *spinal marrow* is in the vertebral canal, extending from the margin of the foramen magnum of the occipital bone to the lower part of the body of the first lumbar vertebra. Above, it is continuous with a part of the brain called the *medulla oblongata* or *bulb*, and below it ends in a long slender filament. The cord lies in the canal surrounded by sheaths, and from its sides issue the thirty-two pairs of spinal nerves, each nerve having an anterior and a posterior root. The length of the cord in an adult is from fifteen to eighteen inches (fig. 30, *c*, *d*).

23. The *brain*, sometimes called the *encephalon*, is situated within the cranial cavity, and it is divided into the *medulla oblongata* or *bulb*, the *pons*, the *cerebellum*, and the *cerebrum*. The *bulb* is the lower part, continuous with the upper end of the cord, and lying on the lower part of the occipital bone, within the *foramen magnum* (see fig. 11). The *cerebellum* occupies the hindermost fossa or depression in the base of the cranium. It is connected

below with the bulb, above with the cerebrum, and in front with the pons. The *pons* is a bridge-like mass of nervous matter above the *bulb*, and related to the two halves of the cerebellum, while nerve fibres pass upwards and downwards connecting the bulb with the cerebrum.

24. The *cerebrum* is the largest part of the brain, and occupies the space represented by the vault of the skull. It consists of two *hemispheres*, the surfaces of which show folds called the *convolutions*, and its internal structure shows certain cavities and enlargements which it is not necessary here to describe. (For illustrations of brain, see NERVOUS SYSTEM.) The brain is protected by membranes, and it is richly supplied with blood.

II. THE ORGANS OF DIGESTION.

25. These form a long canal, the *alimentary canal*, extending from the mouth to the anus. It is situated in front of the vertebral column, commences at the face, passes through the neck and chest, enters the abdominal cavity, in which the chief digestive organs are situated, and ends at the outlet of the pelvis, in front of the coccyx, by the anal orifice. In its upper part the alimentary canal is related to the organs of respiration, and in the lower to the genito-urinary apparatus. The canal is in length from seven to eight times that of the individual, while its diameter is not the same throughout, being in some places contracted to a tube, and in others dilated into a sac or bag. The upper part, above the diaphragm (the musculo-membranous partition between the chest and abdomen), through which the food passes to the stomach, is straight; and the part below the diaphragm is much convoluted, becoming again straight near its termination (fig. 29). The part above the diaphragm includes the *mouth*, the *pharynx*, and the *œsophagus* or gullet (fig. 31). The part below the diaphragm is formed by the *stomach*, the *small intestine*, subdivided

into the *duodenum*, the *jejunum*, and *ileum*, and the large intestine, which is composed of the *cæcum*, the *colon*, and the *rectum*. Connected with the alimentary canal we find certain glandular organs, the chief of which are the *salivary*

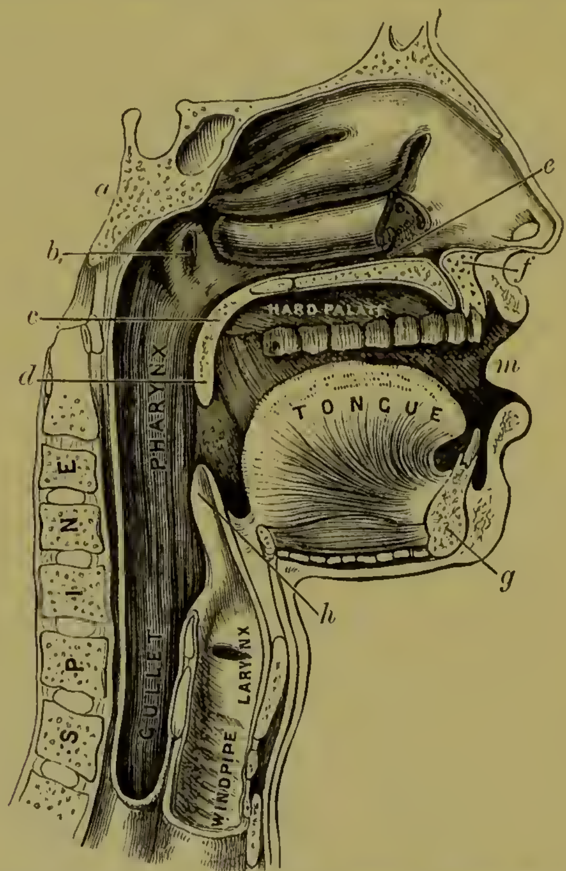


Fig. 31.—Section through Mouth, Nose, &c.:
a, sphenoid bone; *b*, Eustachian tube; *c*, soft palate; *d*, uvula; *e*, nasal passage; *f*, upper jaw; *g*, lower jaw; *h*, epiglottis; *m*, mouth.

glands, the ducts of which open into the mouth, the *liver* and *pancreas*, related to the *duodenum*, and numerous *glands* found in the mucous membrane of the bowel itself.

26. The *mouth* is at the entrance of the digestive canal. It occupies the lower part of the face, and is situated between the two jaws, below the nose, between the cheeks, behind the lips, and in front of the pharynx (fig. 31). It is

concerned in tasting by the tongue, chewing or masticating by the jaws and teeth, insalivation by the saliva formed by the salivary glands, and in articulate speech. The roof of the mouth is formed in front by the hard palate, behind by the soft palate, and its floor is constituted by the tongue and soft parts. From the soft palate two pillars pass down to the back part of the tongue on each side. The posterior orifice of the mouth is the opening of the *fauces* or throat. Its sides are formed by the *pillars of the fauces*, just mentioned, the floor by the base of the tongue, and the roof by the posterior border of the soft palate, with the *uvula* in the centre. Between the pillars of the fauces lie the *tonsils*. These are small gland-like structures.

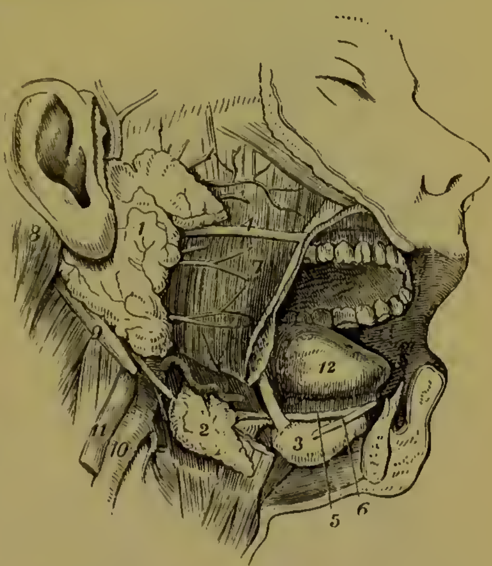


Fig. 32.—The Salivary Glands: 1, the parotid gland; 2, the submaxillary gland; 3, the sublingual gland; 4, Steno's duct; 5, Wharton's duct; 6, Bartholin's duct; 7, masseter muscle; 8, mastoid process; 9, digastric muscle; 10, internal jugular vein; 11, external carotid artery; 12, the tongue.

27. In the floor of the mouth we find the *tongue* (fig. 32, 12), an organ concerned in touch, taste, mastication, and speech. It will be afterwards more fully described.

28. The lining membrane of the mouth contains numerous small glands, the *labial* (lips), *buccal* (cheeks), and *palatine* (palate) glands. There are also six large glandular organs, three on each side, named the *parotid*, *submaxillary*, and *sublingual* glands. The *parotid* is situated below and in front of the lobe of the ear, behind the edge of the ascending part of the lower jaw (fig. 32, 1).

Its duct, called the *duct of Steno*, opens into the mouth between the first and second molar teeth in the upper jaw, 4. The *submaxillary* gland, 2, is situated just behind the body of the lower jaw and its duct, known as the *duct of Wharton*, opens into the mouth by a very narrow orifice below the tongue and behind the incisor teeth of the lower jaw, 5. The *sublingual* gland, 3, consists

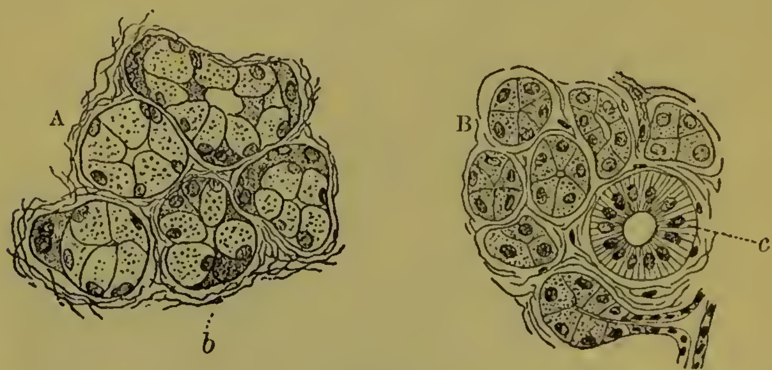


Fig. 33.
Microscopic structure of A, a *mucous*, and B, a serous salivary gland.
For description see text.

of a group of small glands found below the tongue and its excretory ducts, called the *ducts of Rivinus*, seven or eight in number, open in the loose tissue below the tongue. The largest of these is called the *duct of Bartholin.*

The salivary glands differ in the characters of their secretion and also in their structure. When the secretion is thick and mucous-like, as we find in the fluid flowing from the ducts of the sublingual gland, the gland is called a mucous gland ; but when it is thin and watery, as is the case with the fluid flowing from the parotid gland by Steno's duct, the gland is said to be a serous gland. The little pouches of both kinds of glands are lined with living secreting cells. The cells secreting a mucous fluid, as in fig. 33, A, are large and clear, while those secreting a serous fluid are very granular, as in fig. 33, B. Mucous glands have also peculiar cells, like half-moons, adhering to the side of the pouch (fig. 33, A, *b*). The ducts are lined with columnar cells (fig. 33, B, *c*).

29. The *pharynx* is a muscular and membranous bag which forms a space common to the digestive and respiratory passages between the cavities of the mouth and nose on the one hand and the œsophagus and larynx on the other (fig. 31). It changes its form both in swallowing and in the production of voice. Opening from the pharnyx we find the *œsophagus* or gullet, a tube passing from the pharynx into the stomach (fig. 34, *e*). It runs through the neck and the thorax, and passes through the diaphragm to terminate in the stomach. When at rest, the anterior and posterior walls of the œsophagus are in contact, and during swallowing the bolus or mass of food dilates successive portions as it passes along.

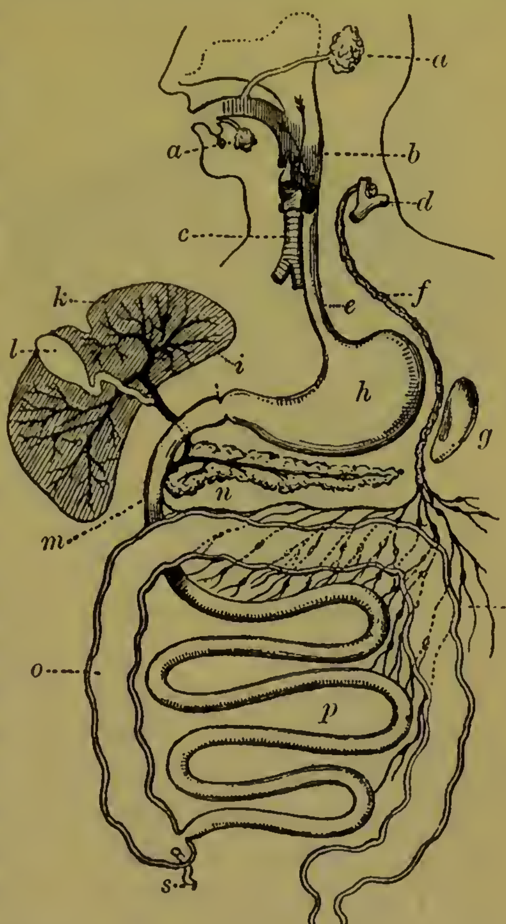


Fig. 34.—Diagram of Digestive Organs: *a*, *a*, salivary glands; *b*, pharynx; *c*, windpipe; *d*, vein; *e*, gullet; *f*, thoracic or chyle duct; *g*, spleen; *h*, stomach; *i*, pylorus; *k*, liver; *l*, gall-bladder; *m*, duodenum; *n*, pancreas; *o*, large intestine; *p*, small intestine; *r*, absorbents; *s*, vermiform appendix.

30. We now reach the *stomach*, a dilatation of the alimentary canal between the œsophagus and the duodenum. It fills the upper part of the abdominal cavity. It lies below

the diaphragm, and is separated by it from the heart. To the right of the stomach lies the liver, an organ which overlaps the stomach to some extent. In front the stomach is covered by the wall of the abdomen, where there is a well-known depression—the *epigastrium*. This depression, sometimes called the *pit of the stomach*, often contains a part of the liver, while the stomach lies lower down, and is below the lower point of the breast-bone. The great end of the stomach, to the left, is in contact with the *spleen*.

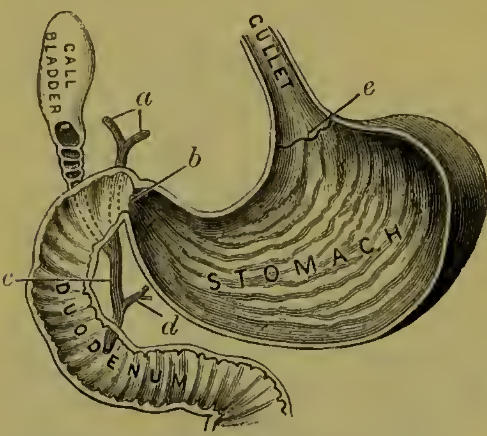


Fig. 35.—Section of the Stomach : *a*, ducts of liver ; *b*, pylorus ; *c*, bile-duct ; *d*, pancreatic duct ; *e*, cardiac orifice.

31. We next pass on to the *intestines*, which are divided into the *small* and the *large*, according to their calibre. The *small intestine* includes that part of the alimentary canal between the stomach and the great intestine, and it is divided into three portions—the *duodenum*, *jejunum*, and *ileum*. The *duodenum*, about ten inches in length, begins at the pyloric aperture of the stomach, to the right of the first lumbar vertebræ, forms a bend which grasps the head of the pancreas, and ends in the jejunum at no very precise point (figs. 35 and 37). The *jejunum* and *ileum*, together about twenty feet in length, fill almost the whole of the abdomen, and this portion of the small bowel is almost surrounded by the large intestine (fig. 29). The *large intestine*, divided into the *cæcum*, *colon*, and *rectum*, is from four to five feet in length, and commences in the right iliac region (or portion of the abdomen a little above

the groin on the right side), passes upwards to the right hypochondrium (lower border of the ribs), then, having reached the liver, it makes a bend and runs transversely from right to left to the left hypochondrium, below the position of the spleen; there again it makes a sharp bend, becomes vertical, and runs down to the left iliac region, where, after twice bending on itself, like the letter S, it dips into the pelvis and ends at the anus. The first part, the *cæcum*, lies in the right iliac region, and between it and the last part of the small intestine, the *ileum*, there is a valve, the *ileo-cæcal valve*, which prevents matters from passing backwards from the large to the small intestine (fig. 36). Connected with the cæcum there is a small narrow tubular structure, like an earthworm, known as the *appendix vermiformis*. The *colon* constitutes the greater part of the great intestine, extending from the cæcum to the rectum, and it is usually divided into the *ascending* or *right lumbar colon*, the *transverse colon* or *arch of the colon*, and the *descending colon* with the *sigmoid flexure*. Lastly, we find the *rectum*, situated in the pelvis and in front of the sacrum and coccyx.

Fig. 36.—Cæcum inflated, dried, and opened to show the arrangement of the valve:

a, termination of the ileum; *b*, ascending colon; *c*, cæcum; *d*, a transverse construction projecting into the cæcum; *ef*, lips of the valve separating the small from the large intestine; *g*, vermiform appendix of the cæcum.

32. We have now shortly to consider the position of the great glands associated with the alimentary canal. The chief of these is the *liver*, which is the largest gland in the body. It lies near the duodenum, below the six lower ribs on the right side, and separated from the

organs in the thorax by the diaphragm. It is an irregularly shaped organ, divided into lobes, weighing in the adult from three to four pounds, and measuring in its longest diameter, the transverse, from ten to twelve inches. It is from four to five inches from above downwards, and about six or seven inches thick, from before backwards. Connected by membranous folds with the wall of the body, it is capable of a small amount of movement, as in inspiration and by change of posture. Its excretory apparatus consists of the *hepatic duct* or true bile duct, the *gall-bladder*, with its duct called the *cystic duct*, and a duct

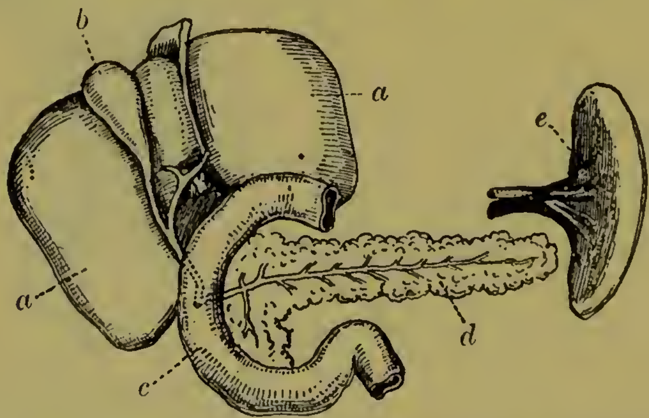


Fig. 37.—Relations of Liver and Pancreas to Intestine : *a*, *a*, liver ; *b*, gall-bladder ; *c*, duodenum ; *d*, pancreas ; *e*, spleen.

known as the *common bile duct*, formed by the union of the cystic duct with the hepatic duct (fig. 37). The *gall-bladder* is a reservoir for the bile, lying on the under surface of the right lobe of the liver, in form like that of a pear, so placed that its broad end looks forwards, downwards, and to the right, and its small end backwards, upwards, and to the left. The common bile duct opens into the duodenum (fig. 37).

33. The *pancreas* is an elongated gland situated transversely and deeply behind the stomach, and in front of the lumber vertebræ. In order to see it, the stomach must be

turned upwards. It is an oblong body, flattened from before backwards, wider at the right end than at the left. The head lies in the centre of the duodenum, while the tail touches the spleen. It weighs from three to four ounces. Behind the pancreas there are several structures separating it from the vertebral column—namely, portions of the diaphragm, the great vein (vena cava) on the right side, and the aorta on the left. To the left of the spine the pancreas is near the left kidney. The duct of the pancreas runs through the substance of the gland, from the tail to the head, and joining the common bile duct, opens into the duodenum (fig. 37, *d*).

34. The *spleen* is a spongy soft organ placed behind and to the left of the great end of the stomach (fig. 37, *e*). It has no duct. This organ, as will be hereafter explained, is concerned in the formation and purification of the blood.

III. THE ORGANS OF RESPIRATION.

35. These consist of (1) the *lungs*, situated in (2) the *thorax* or chest, a cavity having its walls capable of expanding and contracting, thus forming a kind of bellows; and (3) a tubular arrangement by which the air spaces in the lungs communicate with the external air, comprising the *nasal fossæ*, the *pharynx*, the *larynx*, the *trachea* or windpipe, and the *bronchi* or *bronchial tubes*.

36. The *thorax* has been already described (see p. 19). The *pharynx*, also described at p. 43, is common to both the digestive and respiratory passages. The *nasal fossæ*, or *nares*, are the passages by which the air enters the respiratory organs, and they are also the seat, in their upper parts, of the sense of smell (fig. 31).

37. The lungs, two in number, occupy the thoracic cavity, and are placed on each side of the heart (fig. 29). Their size corresponds exactly with the capacity of the thorax, their outer surfaces being always in close contact with

the inner surfaces of the chest wall. The surface of the lung is covered with a fine *serous* membrane which is reflected over the inner surface of the wall of the chest. Two serous membranes, the layers of the *pleura*, are thus in contact, and the space between them (which in health can scarcely be said to exist, seeing both surfaces are in contact) is called the *pleural cavity*. Each lung is shaped like a cone, deeply depressed on the inner side, with the apex above and the base below. The left lung is divided into two lobes, a superior and inferior; and the right into three lobes, a superior, middle, and inferior. The inferior lobe of each lung forms the base, and the base is concave, moulded on the convexity of the diaphragm. The superior lobe forms the apex, which projects into the neck above the first rib. The inner surface of each lung shows what is called the *root of the lung*, that is, the part at which it communicates with the trachea, through the bronchi, and by which blood-vessels enter into and issue from the lung. Behind the root there is a space called the *posterior mediastinum*, in which we find, on the left side, the descending aorta, upper part of the thoracic duct, and left vagus nerve, and on the right side the azygos vein, the œsophagus, the lower part of the thoracic duct, and right vagus nerve. In front of the root we find another space, called the *middle mediastinum*, in which the heart rests.

38. The *trachea*, or windpipe, is the tube passing from the larynx to the air tubes in the lungs, or *bronchi*. From four to five inches in length, it extends from about the level of the fifth cervical to the third dorsal vertebra, almost in the median line of the neck, and it divides below into the two bronchial tubes (fig. 38). Near its upper end it is covered by a gland called the *thyroid gland;* an important artery, the *common carotid artery*, and a nerve called the *vagus* or *pneumogastric*, are in contact with it

on either side. The trachea is flattened behind, and lies almost in front of the œsophagus (see fig. 34). In the thorax, it lies in the space extending up from the root of the lung called the *superior mediastinum ;* behind it, we find the œsophagus, which separates it from the spinal column, and it is surrounded by many glands and vessels and loose connective tissue. It divides into the *right and left bronchus*, tubes passing one to each lung. These bronchi divide and subdivide in the lung, becoming smaller and smaller, as will be afterwards described.

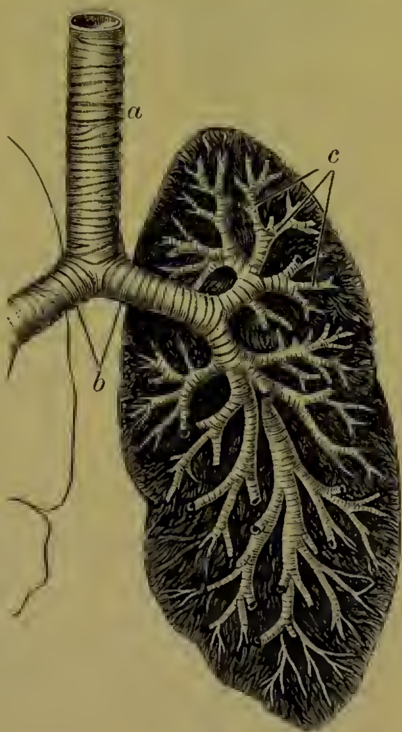


Fig. 38.
Windpipe and one of the Lungs : *a*, windpipe ; *b*, bronchi ; *c*, bronchial tubes.

39. The *larynx* is a box formed of various pieces of cartilage movable on each other. It is in the middle line of the neck, opening into the pharynx above and into the trachea below. It is the upper end of the respiratory tube, and specially concerned in the production of voice. The larynx is very prominent in the throat of the male, forming the *pomum Adami*, or Adam's apple ; in the female it is smaller. The differences in size affect the pitch of the voice in the two sexes (fig. 31).

IV. THE GENITO-URINARY ORGANS.

40. These consist of two secreting glands called the *kidneys ;* two ducts, the *ureters ;* a reservoir for the urine, the *bladder ;* and an excretory canal, the *urethra.*

41. The *kidneys*, of well-known form, are deeply placed in the lumbar region, one on each side of the vertebral column. They are usually covered with fat, and are connected with vessels which enter and emerge from them. Each kidney is from three and a half to four inches in length, two inches in breadth, and one inch in thickness, weighing from two to four ounces. The right kidney is a little lower than the left, owing to the presence of the liver, by which it may be covered. It may also touch the gall-bladder. On the right side, the kidney is also in close relation with the duodenum. On the left side, the kidney is near the spleen and the great end of the stomach. The structure will be afterwards described. The duct that carries the urine from the kidney is called the *ureter*, passing from the concave side of the kidney to the bladder. It is about the thickness of a crow's quill. It runs down to the level of the base of the sacrum, where it enters the bladder.

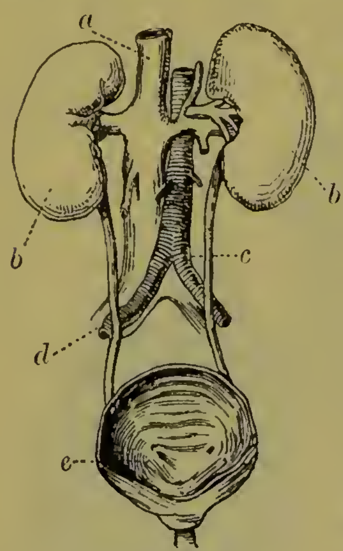


Fig. 39.
Urinary Apparatus: *a*, inferior vena cava; *b*, *b*, kidneys; *c*, aorta; *d*, ureter; *e*, bladder.

Immediately above each kidney there is a small gland, having no duct, known as the *suprarenal capsule.* These bodies have to do with the elaboration of the blood. The *bladder* lies in the pelvis, in the middle line, behind the pubis. When empty it lies in the pelvis, but it rises into the abdominal cavity as it fills. It is oval in form, the great end being directed upwards. The anterior wall is behind the symphysis pubis; the posterior wall, in the male, is in front of the rectum, and in the female in front of the uterus, or womb.

V. THE ORGANS OF THE CIRCULATION.

42. These consist of the *heart*, *arteries*, *capillaries*, and *veins*. The general position of the heart has already been indicated (pp. 36 and 47), and the arrangement of the organs of the circulation will be best considered when we discuss the circulation of the blood.

QUESTIONS.

21. Describe the general position in the body of the cerebro-spinal axis.
22. What do you mean by spinal cord and medulla or bulb? What is the connection of the spinal nerves with the spinal cord?
23. What are the parts of the encephalon?
25, 26. Describe the parts forming the mouth and found in the mouth.
26. Describe what you see if you open your mouth wide before a looking-glass.
28. Describe the position and ducts of the salivary glands. Make a drawing showing the different appearances of a mucous and a serous gland.
29. Give an account of the pharynx, showing its position and the openings communicating with it. Show by a drawing the position in the neck of the trachea and œsophagus.
30. Make a drawing of the shape of the stomach.
31. Give a short account of the position of the different parts of the alimentary canal. What and where is the ileo-cæcal valve? What is its use? Where is the appendix vermiformis?
32. Give an account of the position of the liver. What are its ducts? Where is the gall-bladder?
33. What is the position of the pancreas?
35, 36, 37. What do you understand by the pleural cavity?
38. What is the origin, course, and mode of termination of the trachea?
41. Give an account of the position and relation to other organs of the two kidneys.

CHAPTER II.

CHEMICAL CONSTITUTION OF THE BODY, AND THE CHEMICAL ACTIONS OCCURRING IN IT.

In connection with this department of physiology, we shall briefly discuss (1) the chief elementary constituents of the human body; (2) the chief compounds which have been isolated by the chemist; and (3) the chief chemical changes which occur in the living organism.

43. If the body, or a portion of it, were submitted by a chemist to complete analysis, it could be resolved into the chemical *elements* of which it is composed, or into *compounds* formed by certain of those elements. By an element is meant a substance that cannot be further decomposed by any means at present known to the chemist. Thus carbon, oxygen, hydrogen, and nitrogen are elements. By no known means can carbon be resolved into other bodies; and the same remark applies to all elements. Sixty-nine or seventy elements are known to exist, and of these not more than eighteen or twenty have been found in living matter. Chief among these are the four already named —carbon, oxygen, hydrogen, and nitrogen. Carbon at ordinary temperatures is a solid. The other three exist in ordinary circumstances as gases; but at very low temperatures, and under great pressure, they also may pass into the liquid, and finally into the solid state. Oxygen unites readily with hydrogen, carbon, and nitrogen, to form compounds; hydrogen and carbon do not unite with other substances readily at ordinary temperatures; and nitrogen is remarkable for its inertness—that is to say, it does not unite readily with other bodies, and the compounds it forms are not very stable, but are liable to decomposition. Seeing that no matter can exist in the living state that

does not contain nitrogen, and that living matter is chemically in a state of constant flux or change, the loose bonds that nitrogen forms with other substances may explain the instability and tendency to change so characteristic of living matter.

ELEMENTARY CONSTITUENTS.

44. The principal elementary constituents, then, are carbon, oxygen, hydrogen, and nitrogen. Those next in importance, or at all events in frequency, are sulphur, phosphorus, chlorine, sodium, potassium, calcium, and iron. The first four are met with in all the fluids and solids of the body; sulphur in albuminous matters, blood, and in most secretions; phosphorus in blood, nervous matter, bone, the teeth, and in most liquids; fluorine in bone and the teeth; chlorine everywhere; sodium everywhere; potassium in the muscles, coloured blood-corpuscles, nervous matter, and secretions; calcium in bone, teeth, and fluids; magnesium usually accompanies calcium; iron in the colouring matter of the blood, bile, urine, &c. The rarer bodies are silicon, lithium, manganese, copper, and lead. It is interesting to classify these substances—the bricks of which the edifice is composed—according to the method of the chemist. Thus, of the *hydrogen* group, we find hydrogen and chlorine; of the *oxygen* group, oxygen and sulphur; of the *nitrogen* group, nitrogen and phosphorus; of the *carbon* group, carbon and silicon; of the *alkaline bodies*, sodium and potassium; of the *alkaline earths*, calcium and magnesium; and of the *metals*, only one, iron. Of fifteen non-metals, nine are represented; while of the fifty-four metals, only one, *iron*, is indispensable, and other three or four may be present—namely, manganese, copper, and lead. The earth's crust consists chiefly of oxygen, silicon, aluminium, iron, calcium, magnesium, sodium, and potassium; water is formed of oxygen and hydrogen; and

living matter contains all of these elements, with several in addition.

COMPOUNDS.

45. The elements are so combined in living matter as to constitute *compound bodies*, which may be separated as such by chemical processes. Such compounds are termed *proximate principles*. For example, phosphate of lime is a proximate constituent of bone, but phosphoric acid and oxide of calcium, which together form phosphate of lime, do not exist individually in bone. Chief among these proximate constituents is *water*. There are two classes of compounds: *Inorganic*, such as water and phosphate of lime, and *organic*, such as albumin and urea.

Inorganic Compounds.

46. These may be divided into water, inorganic acids, inorganic bases, and salts.

Water forms about two-thirds of the weight of the body, so that a body weighing about 165 lb. will contain about 110 lb. of water. Certain tissues contain very little water, such as the substance of tooth, bone, &c.; whereas others, such as brain-matter and muscles, contain a great amount.

Inorganic Acids.—These are hydrochloric, hydrofluoric, phosphoric, sulphuric, and silicic. None of these occur in the free state (except the first in the juice of the stomach), but are combined with sodium, potassium, calcium, &c. One of the most important substances belonging to this group is *carbonic acid*. It is formed by a union of carbon with oxygen, and at ordinary temperatures and pressures it is a colourless gas. It can be liquefied and solidified by pressure or cold, or by both combined. Carbonic acid is one of the chief products of combustion or burning, the carbon of the substance uniting with the oxygen of the air.

It is also formed in large quantity by all living tissues, whether of plants or animals. All living matter breathes—that is to say, it takes in oxygen, and this gas unites with the carbon of the tissues (many complicated chemical processes occurring) to form carbonic acid, which is then thrown out. If we blow air from the lungs into lime water, the water becomes white and turbid from the formation of carbonate of lime by the carbonic acid of the breath uniting with the lime in the lime water. The air contains about ·04 volumes per cent. of carbonic acid—that is to say, in 100 volumes of air we would find, not one volume, but $\frac{1}{25}$th of one volume. Thus 100 cubic inches would contain $\frac{1}{25}$th of a cubic inch. Carbonic acid also exists in water of rivers and springs (more especially the latter) and in the ocean. The gas in the air is decomposed by the green colouring matter of plants under the action of the sun's rays, the carbon being built up into chemical compounds forming the tissues of the plant, while the oxygen is liberated. This must be distinguished from the true breathing process of the plant, which is like that of animal tissues, oxygen being taken in and carbonic acid given out.

Inorganic Bases.—These are soda, potash, ammonia, lime, and magnesia. None occur free, but are combined with acids to form salts. *Ammonia* is a compound composed of nitrogen and hydrogen. Thus ammonium (the base) consists of four volumes of hydrogen united with one volume of nitrogen, and we may regard ordinary ammonia as being formed of three of hydrogen with one of nitrogen. Ammonia is a gas. It is readily soluble in water, and, acting as a base, it forms salts, such as ammonium phosphate, sulphate, and chloride, &c. As will be seen later on, many complex organic bodies that contain nitrogen are bodies of the nature of ammonia, or rather they are compound ammonias. The important fact to remember is that it is from ammonia that the living matter in plants

receives the nitrogen that is absolutely necessary for the phenomena of vitality. In turn, the living matter of animals receives its nitrogen from the nitrogen of plants.

Salts.—These are numerous, but the chief are chloride of sodium, chloride of potassium, chloride of ammonium, fluoride of calcium, phosphates of sodium and potassium, phosphate of calcium, phosphate of magnesium, and sulphates of sodium and potassium. The most important as regards amount is the chloride of sodium, or common salt, of which about 3086 grains, or over six ounces, exist in an average human body.

Organic Compounds.

47. Such may be divided primarily into those containing nitrogen, or *nitrogenous*, and those not containing nitrogen, or the *non-nitrogenous.* The nitrogenous (grouped under the name of *proteids*) include albumins, globulins, and albuminoids. The non-nitrogenous include certain organic acids, animal starch and the sugars, the fats, and the alcohols. All proteids consist of carbon, hydrogen, oxygen, nitrogen, and sulphur, and there are certain allied substances containing phosphorus. The albumins comprise such substances as common *albumin* (familiar as white of egg), found in blood, chyle, lymph, &c., and *casein*, obtained from milk. The globulins, of which *myosin*, in muscle, is an example, occur in muscle, blood, &c. The albuminoids are so termed because, while they have properties peculiar to each, they have certain general properties resembling those of the albumins. The chief are *gelatin*, obtained by boiling skin, sinew, &c. ; *chondrin*, got by boiling cartilage ; and *elastin*, made by the prolonged boiling of elastic tissue. There are other nitrogenous bodies which do not form a constituent part of any tissue, but as they are made in the economy by those chemical dissolutions of more complex substances on which vital activity

would seem largely to depend, they are always found either in the solids or in the excretions. The chief are *urea* and *uric acid*, two substances in the urine which will be afterwards described; *leucin*, *tyrosin*, *cystin*, and *taurin*, found in bile; *kreatin* and *kreatinin*, existing in muscle-juice; and *lecithin* and *cerebrin*, found in nervous matter. These will be subsequently referred to in treating of the juices in which they occur.

48. The non-nitrogenous substances, consisting of carbon, oxygen, and hydrogen, in varying proportions, comprise four different kinds of bodies—namely :

Organic Acids.—Certain organic acids, which are usually united with bases forming salts. The chief of these are *carbonic*, *formic*, *acetic*, *propionic*, *butyric*, *palmitic*, *stearic*, *oleic*, *lactic*, *oxalic*, *succinic* acids, &c.

Carbo-hydrates.—These are bodies so called because they consist of carbon united with hydrogen and oxygen in the proportions in which these latter exist in water. Thus, take starch as an example. Water is formed of hydrogen and oxygen in the proportion of 2 to 1, and we write H_2O—that is, hydrogen 2 and oxygen 1. Starch is $C_6H_{10}O_5$—that is, 6 of carbon, with hydrogen and oxygen in the proportion of 2 : 1, or $H_{10}O_5 \div 5 = 5H_2O$. Animal starch or *glycogen* has the same chemical formula as common starch. It is found in the liver and muscles, and also in the tissues of the embryo. Of sugars there are four varieties to be met with in the body: *maltose* (malt sugar), and *glucose* (grape-sugar), in the alimentary canal; *inosite* (muscle-sugar—not a true sugar), found chiefly in the heart; and *lactose* (milk-sugar), found in milk.

Fats.—Chemically considered, a fat is glycerin in which one, two, or three of the atoms of hydrogen are replaced by the radicle of a fatty acid. Thus the chemical representation of glycerin is $C_3H_8O_3$, and 3 of H's may be replaced by the radicle of a fatty acid. This radicle is a group

of atoms, such as $C_{18}H_{35}O$, existing in stearic acid. Take ordinary beef fat. It consists chiefly of stearin, and stearin is glycerin in which 3 of the H's are replaced by three of the group ($C_{18}H_{35}O$). This gives us $C_3H_5(C_{18}H_{35}O)_3O_3$. If stearin is boiled with an alkali such as soda, the alkali unites with the fatty acid to form a *soap*, and glycerin is set free. It is especially worthy of notice that a fat contains bulk for bulk much more carbon in proportion to the oxygen than a carbo-hydrate. Thus in starch we have 6 of carbon to 5 of oxygen, whereas in fat we have 57 to 6—that is to say, in starch the proportion of C to O is about 1 : 1, but in fat it is nearly 10 : 1. To burn a given weight of fat, therefore, more oxygen is needed than to burn the same weight of starch. Carbonic acid will be produced in both cases, but more with fat than with starch, and, lastly, as heat is evolved by combustion, fat when burned will give out much more heat than would be evolved by burning the same weight of starch. All this is of importance in considering the values of fat and starch in foods for purposes of heat production. Of such compounds in the body there are three—*stearin*, *palmitin*, and *olein*, which are found in all fatty matter. Four or five pounds of fatty matter may be found in a body of average size and weight.

Alcohols.—In the body only two compounds are known which physiological chemists refer to this group—*glycerin*, which is the basis of all the fats, and *cholestrin*, which exists in bile, and in a solid state forms the chief constituent of gall-stones.

Waste Bodies.—Numerous substances are thrown out of the body as useless, which would be even injurious if they were allowed to accumulate. Of these some are nitrogenous, while others are non-nitrogenous. The chief representative of the non-nitrogenous waste bodies is *carbonic acid*, already referred to; and the most important of the nitrogenous group is *urea*.

49. *Urea.*—This body, found chiefly in the urine, is met with in small amount in blood, and also in many of the liquids and solids of the body. It is a crystalline substance in the pure state. It is inodorous, and has a bitterish saline taste. It is readily soluble in water. It consists chemically of 1 atom of carbon, 2 of nitrogen, 4 of hydrogen, and 1 of oxygen, and chemists represent it by the formula CN_2H_4O. The importance of urea arises from the fact that it is the substance by which nearly the whole of the waste nitrogen of the body is eliminated. The amount of urea thrown out of the body is influenced chiefly by the quantity of proteid taken in the food, and it is interesting, therefore, to compare the percentage composition of such a proteid as the albumen of white of egg with urea. Thus in two parts of

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.
Proteid......	53	7·3	23·04	15·53	1·13
Urea.........	20	6·6	26·67	46·67	...

Urea therefore contains about three times as much nitrogen as proteid ($15{\cdot}53 \times 3 = 46{\cdot}59$), or 100 parts (grains or ounces) of urea contain as much nitrogen as 300 parts of proteid.

CHEMICAL CHANGES IN THE LIVING ORGANISM.

50. A little reflection will at once indicate how difficult it is to attempt to investigate the chemical changes occurring in a living tissue or in a living being. True it is, we may collect and analyse every excretion, we may examine the air before and after breathing, and we may analyse the food, and give such food as we think may vary the conditions of the inquiry ; but these procedures throw little light on the chemical compositions and decompositions in the tissues and organs which we know do take place. Still, without direct evidence perhaps, but supported by all the known facts and justified by all analogies, we can say that in the

body the chemical changes may be classified as follows: Oxidations, decompositions, reductions, syntheses, and fermentation or zymolysis.

51. *Oxidations.*—These constitute the great majority of the chemical changes occurring in the body. By oxidation is meant the union with oxygen of one or more constituents of a complex substance, so as, in most cases, to form one less complex. Oxidations may go on step by step, each gradation being simpler than the one immediately preceding it. Thus the terminal products of the oxidation of albuminous substances are urea, water, and carbonic acid, and of the fats, water and carbonic acid. By artificial processes of oxidation the chemist has succeeded in producing many simpler compounds, and thus he has imitated the processes going on in the body. From albuminous matter he has formed leucin, tyrosin, glycocoll; and from uric acid, urea, oxalic, and carbonic acids, &c. The agent in processes of oxidation is, of course, oxygen introduced by respiration. These processes seem to be essential to the production of all vital actions.

52. *Decompositions.*—By decomposition is meant the splitting up of a substance into two or more components, the combined weight of which represents exactly that of the compound. Thus one of the acid substances found in the bile, taurocholic acid, splits up into taurin and cholalic acid, and the sum of the atomic weights of the latter two is exactly equal to that of the former. Some substances lose one or more molecules of water, and thus become chemically changed. For example, kreatin and kreatinin, compounds found in muscle-juice, differ only by a molecule of water. Such a process of abstracting water is called *dehydration*. Recently it has been conjectured that some processes occurring in the body are what the chemist terms *dissociation*, by which is meant a decomposition occurring at a certain temperature and pressure or tension,

in which the substances which have been separated will re-unite to form the primitive compound when the former conditions as to temperature and pressure are re-established. Thus the colouring matter of the blood, called hæmoglobin, united with oxygen in the lungs, becoming oxy-hæmoglobin, and gives up the oxygen again to the tissues, as the blood circulates through these, again becoming hæmoglobin.

53. *Reductions.*—By the term reduction is meant the removal of oxygen from a complex substance. It rarely happens apparently in the animal body.

54. *Syntheses.*—The formation of compound bodies by a process of building up or synthesis is less understood than processes of decomposition. Sometimes this process simply consists of one of hydration—that is, a compound unites with water to form a more complex body. Thus kreatin combines with a molecule of water and becomes kreatinin. Chemists have synthetically produced many of the substances formed naturally in the body, such as urea, hippuric acid, taurin, sarcosin, kreatin, oxalic acid, succinic acid, acetic acid, &c., but little is known as to the steps by which these bodies are formed in the body.

55. *Ferment-like Actions, or Zymolysis.*—A true *ferment* is a living organism that has a powerful effect on certain kinds of matter, splitting it up into simpler bodies, while at the same time the organism constituting the ferment grows and multiplies. The common yeast used in breweries and distilleries is an example. Yeast consists of minute vegetable organisms or cells, constituting a group of the fungi, and known as *Saccharomycetes cerevisiæ.* These cells live on the sugar in the wort, changing it into alcohol and carbonic acid chiefly, although small quantities of other substances are formed. Certain cells in the body, especially the cells of certain glands, also produce substances which act like ferments, but the difference is that the sub-

stance formed by the cell is not alive, but in a peculiar state of molecular activity. The substance thus formed in living cells is called a *zymogen*, to distinguish it from a true ferment. The zymogen, in certain circumstances, yields a ferment-like body called an *enzyme*, and the action of the *enzyme* is called *zymolysis*, to distinguish it from true *fermentation*. During the process the enzyme does not increase in quantity. Both ferments and enzymes are killed by the temperature of boiling water, and even at a lower temperature. Any substance that arrests or destroys growth of living organisms, like corrosive sublimate or thymol, will check fermentation, but will have no effect on zymolysis. Many examples of zymolytic changes occur in the body. The *enzymes* are produced by living cells in certain glands. Thus we have *ptyalin*, the enzyme of the saliva, formed in the salivary glands; *pepsin*, the enzyme formed in the gastric glands of the stomach, &c. Their chemical constitution resembles that of albuminous matters, but they contain no sulphur. The following are examples of such processes: (1) The transformation of starch into dextrin and into glycose, produced by the action of ptyalin and pancreatin, and also under the influence of all albuminous matters, especially in the act of decomposition; (2) the transformation of fats into fatty acids and glycerin, accomplished by a pancreatic enzyme; and (3) the transformation of albuminates into peptones, or soluble modifications of proteids, as happens under the action of the pepsin of the gastric juice and of a pancreatic enzyme. For the accomplishment of zymolysis certain conditions of moisture and temperature are required. These conditions exist in the animal body, so that the chemical transformations of food during the process of digestion are due to the action of soluble enzymes. Probably also, similar changes occur in the more obscure processes of nutrition, and in the actions of certain glands,

such, for example, as the liver, where apparently an enzyme is formed which converts glycogen or animal starch into sugar.

56. *Instability of Organic Compounds.*—Certain proximate principles are the same as those met with in the crust of the earth, or in the water of oceans and rivers, such as chlorides of sodium and potassium, sulphates of soda and potash, phosphates of soda, potash, lime, and magnesia. The proximate principles more characteristic of plants and of animals are composed of carbon, hydrogen, and oxygen, such as starches, sugars, fats; or are formed of carbon, hydrogen, oxygen, nitrogen, and sulphur or phosphorus, such as albumin in white of egg and the gluten of flour. Compounds formed of three elements only have, especially in the dry condition, a considerable amount of stability; on the other hand, compounds containing four or more elements are much less stable. They tend to fly to pieces. They exist only within a limited range of temperature and pressure, and under the action of bodies in a more active state (the *enzymes*) the complex organic substance falls to pieces, not resolving itself into its elements, but into simple groups of elements. Thus egg-albumen may split up into a large number of simpler bodies—leucin, tyrosin, &c.—and these last into still simpler, until we reach water and urea. This instability, or tendency to change, is one of the essential conditions of life. A living body is continually undergoing a series of chemical changes, of composition and decomposition, building up and pulling down, as a result of which there is an incessant renovation of the molecules of the organism. Chemical changes are a necessary condition of the action of living matter, or it may be said that *the living state is always associated with chemical change;* part of the living matter dies, is decomposed (or rather its decomposition is its death), and the dead matter is then thrown out of the organism. New matter is added

from without, and then there is a perpetual exchange between the organic or living world and the inorganic or dead world, which may be termed a *circulation of matter.*

Questions.

43. Describe the general characters of the chief elements of which the body is composed.
44. Classify the chemical elements of which the body is composed.
45. What is understood by the term 'proximate principle?'
46. What amount of water occurs in the body? What are the acids found in the body? What are the chief bases and salts found in the body?

46, 47. What is the difference between an organic and an inorganic proximate constituent?

47. Mention some of the chief nitrogenous bodies found in the tissues. Where are gelatin, chondrin, and elastin found?
48. What is a carbo-hydrate? Give examples. What is the chemical nature of a fat? Why is a fat a better source of heat than a carbo-hydrate?
49. What is the chief nitrogenous waste matter found in the urine? Describe the chief physical characters of urea. Show the relation of urea to a proteid.

50, 51, 52, 53, 54. Enumerate the chief chemical processes occurring in the body.

51. What is an oxidation? What are the last products of the oxidation (*a*) of proteids, and (*b*) of carbo-hydrates and fats?
52. What do you mean by dehydration and dissociation?

53, 54. What is understood by synthesis and reduction?

55. Distinguish between zymolysis and fermentation. What does the yeast plant do? What is an enzyme? Mention the chief zymolytic processes occurring in the body.
56. What do you understand by the 'instability of organic compounds?' What is the 'circulation of matter?'

CHAPTER III.

THE BODY IN ACTION.

57. Introductory.—Having considered the structure of the body, and the nature of the chemical changes happening in it, we are now in a position to view its mode of action as a whole. In the first place, we see that the animal body moves apparently spontaneously. Animals run, leap, walk, fly, swim; they move about from place to place; and they may move only one part of the body, as when we open or close the mouth, or lift a pencil from the table with the fingers. We soon observe, also, that there are movements occurring in the body itself, often rhythmic in their character (that is to say, they are repeated over and over again), as the movements of the thorax in breathing, and the beating of the heart, which we can feel by placing the hand over the left side. Thus one of the most remarkable characteristics of the living body is *movement*.

58. Heat.—We next notice that the body of the higher animals—and we take as an example the human body we are specially studying—is *warm*. Suppose we place the bulb of a thermometer in the armpit, and leave it there for a few minutes, we shall find that in health it registers a temperature of about 98·4 degrees on the Fahrenheit scale, and a few observations made on a healthy person would convince us that this temperature does not vary much (not more than a fraction of a degree) during the twenty-four hours. Still more remarkable, we would find that the change of temperature is very slight at different seasons of the year. During the heat of summer, or the cold of winter, we would not find a greater change, up or down, than a degree or a fraction of a degree. The body of man,

therefore, is not only warm, but it *maintains a uniform temperature*, although the temperature of the external air may vary very much. Now, a hot body cools by giving off heat to surrounding objects; and if the human body is hotter than the surrounding air, it must constantly be losing heat. But the temperature is uniform, as we have seen, although the temperature of the surrounding air may change. It follows, therefore, that a quantity of heat must be produced in the body to make up for the quantity lost. This shows us two things: (1) that the living body produces heat; and (2) that there are arrangements for maintaining a uniform temperature—in other words, for balancing the income and the output of heat.

59. FOOD.—Further, we find that a living body requires *food*. If an animal is starved, it becomes thinner and thinner, the fat being used up in the first instance, and in course of time all the tissues become wasted. During starvation an animal feeds upon itself. In ordinary circumstances, however, this wasting is prevented by new supplies of material introduced in the form of food. Along with that which is usually called food, the process of breathing introduces into the body large supplies of oxygen, and this oxygen is as necessary as food for the well-being of the body. No animal will live in an atmosphere where there is no oxygen. *Food and oxygen are thus introduced daily.*

60. WASTE OF MATTER.—Not only is new matter daily introduced, but old matter is daily removed from the body. This we may call *waste matter*. This waste matter is of various kinds, and it is separated by various organs. Thus we find the LUNGS separating *water* and *carbonic acid;* the SKIN, *water*, *carbonic acid*, *saline matters*, and certain *organic substances*, chiefly of a fatty nature; the LIVER, *water*, *saline matters*, some *colouring matters*, and some *organic substances;* and the KIDNEYS, *water*, *nitrogenous substances*, chiefly *urea*, *saline matters*, *colouring*

matters, and to a small extent *carbonic acid*. Certain matters are also separated by the *intestinal canal*, and, chief among these, the materials of food that have not been digested or absorbed; but although the latter have passed through the intestinal canal, they have never really entered into, or become part of, the body. If we examine these waste substances carefully, we find they may be grouped thus: water, saline matters, non-nitrogenous matters, and nitrogenous matters. As most of the water and saline matters are introduced in the food, they can scarcely be classed as substances arising from the tear and wear of the tissues. The chief non-nitrogenous waste substance is *carbonic acid*, given off mainly by the lungs, and the representative nitrogenous substance is *urea*. Both of these substances may be regarded as waste products. As we have seen, carbonic acid is composed of carbon and oxygen, and the amount of carbonic acid given off daily, chiefly by the lungs, is the measure of the amount of carbon eliminated. Thus an adult doing a moderate amount of work gives off by the lungs about 3600 grains of carbon; to this we must add about 300 grains separated by the skin, and also the carbon in the urea and other nitrogenous waste matters, amounting to about 120 grains, or $3600 + 300 + 120 = 4020$; or, say, 4000 grains. In a similar way, the amount of urea is the measure of the quantity of nitrogen given off. An adult man eliminates about 300 grains of nitrogen. The substances eliminated contain about 90 grains of hydrogen and about 10,000 grains of oxygen. Add to this about 480 grains of saline matters, such as chlorides, sulphates, and phosphates of soda, lime, magnesia, &c., separated by the kidneys and bowels, and we find a total of nearly 15,000 grains, or about 2 pounds' weight, of matter eliminated from the body daily.

61. Waste of Energy.—When the body works, it

expends *energy*. This it does chiefly in two ways: (1) as heat, and (2) as mechanical work. We have already considered heat. As regards mechanical work, the body expends energy in moving about, as in locomotion, in lifting weights, and, in short, in many ways of doing work, as in the daily life of a labouring man. All this expenditure is in doing what we may call outside work; but the body, considered as a machine, does inside work as well. Thus work is done by the beating of the heart, and by the movements of respiration. The body is thus always losing energy, just as it is always losing matter. It is possible, also, to measure this expenditure of energy, and to express it in terms we can understand. The unit of energy usually employed is the foot-pound—that is, the amount of energy required to lift one pound one foot high. Suppose we take the case of a labouring man doing a fair amount of hard work during eight hours. During 24 hours the amount of work done by his heart may be stated at 361,500 foot-pounds; add to this the work done in the movements of respiration, 84,591 foot-pounds; to this, again, add the work actually done during eight hours of labour, 903,750 foot-pounds; and, last of all, add the energy represented by the amount of heat produced by his body during 24 hours, 4,482,600 foot-pounds. The total energy expended in 24 hours thus amounts to nearly 5,000,000 foot-pounds. To make up for this daily expenditure of energy by an adult man, fresh energy must be introduced. This is accomplished by the food. Food may be regarded as matter containing energy stored up in it, or, as it is expressed, energy in the potential state, and it is liberated by the body, appearing as motion and heat. Now we can estimate the income and the output of matter daily, and a balance can be struck, showing that, when the body remains approximately at the same weight from day to day, the amount of the income is that of the output.

In like manner, we can estimate the amount of energy stored up in a given quantity of food. If we burn an ounce of starch, we can measure the amount of heat produced, and from that calculate the amount of energy represented. If this be done with the diet of a labouring man, who expends in 24 hours the energy above indicated, we find that it supplies all the energy required; that is to say, we can strike a balance as regards income and output of energy, just as we can strike a balance between income and output of matter.

62. THE PHENOMENA IN A MUSCLE.—The facts stated generally in the last few paragraphs will be better understood if we consider shortly some of the phenomena that happen in a living muscle. As we have seen, muscles, by their power of contracting, are the organs by which the movements of the body are effected. Each muscle has its own proper work to do. Take, for example, the biceps muscle in front of the upper arm, which, by its contraction, bends or flexes the forearm on the arm at the elbow joint. If we perform this movement repeatedly at short intervals, we soon have a sense of *fatigue*, which passes off if we stop the movement and allow the muscle to rest for a sufficient time. Dissection shows us that the muscle is supplied with nerves that can be traced to the spinal marrow, and nerve fibres can be followed up to the brain. If these nerves were divided, we could not voluntarily—that is to say, by an effort of the will—cause the muscle to contract, or, in other words, we could not bend the forearm on the arm at the elbow joint. The nerves, then, are the agents by which the muscle is caused to contract, and what is termed a *nervous impulse* passes along the nerve fibres from the brain to the muscle; there the impulse sets up some changes in the muscle, and the result is a *muscular contraction*. Now, a muscular contraction is a movement; in other words, the muscle expends or liberates energy as

movement. Further, if we examine by proper methods the muscle while it contracts, we find it becomes *warm*—that is to say, the muscle liberates energy as *heat*. Energy can only be set free when *chemical changes* occur in the muscle, and when we look for such changes, there is not much difficulty in finding evidence of their existence. Thus we find that a muscle uses up oxygen and produces carbonic acid. In addition to the production of carbonic acid, the muscle becomes acid, from the formation of an acid called sarcolactic acid, and numerous waste nitrogenous matters are formed, such as kreatin, sarcosine, &c., bodies found in the juice of meat, such as Liebig's extract. There is also evidence that certain bodies are used up by the muscle. Thus it requires oxygen. The muscle also uses a peculiar carbo-hydrate formed in the liver called glycogen, and it uses also various proteid substances. The chemical phenomena happening in a muscle are essentially those of oxidation—that is, the union of oxygen with the carbon of the tissue of the muscle. The process is not so simple as here stated. Carbon does not simply unite with oxygen. Numerous intermediate bodies are formed in the process, but the ultimate results are mainly the formation of carbonic acid and nitrogenous waste bodies. Thus we see that in a muscle, when it works, *energy is set free as motion and heat, and waste bodies are formed.* The muscle may be taken as the type of other kinds of tissues. Heat is probably always liberated, and chemical products are no doubt always formed, but outward visible motion may not be one of the phenomena.

63. THE BLOOD.—Tissues, during their activity, being thus the seat of active chemical changes, in which certain substances are used up and others are formed, it is clear that there must be some means by which these new materials are brought to the tissues, and by which the waste substances are removed. This is accomplished by

the blood, and by the circulation of that fluid in the tissue. Every tissue is more or less supplied with blood-vessels, and the blood circulating in minute thin-walled tubes, the *capillaries*, is brought into close proximity to the elements of the tissues. From these minute vessels a fluid passes out, holding in solution materials required by the tissues for their nourishment. This fluid, called *lymph*, bathes the tissues, so that the elementary tissues, the cells and fibres, live in a fluid. From this fluid they take up oxygen and nutritive materials, such as proteids, fats, carbo-hydrates, saline matters, and water, and thus the living elements are built up. The constructive process is sometimes said to be *anabolic*, a word meaning building up. Thus we may speak of anabolic processes repairing a muscular fibre, when it has been worn out and exhausted by the activity called contraction. When a tissue has thus been built up, we may suppose it to be fit for its special function, and this function is discharged under the action of some kind of *stimulus*. In the case of muscle, the normal stimulus is the action of the nervous impulse already alluded to. Chemical changes are thus set up in the muscle, and waste products are formed. The process is now one of pulling down, or, as it is called, *katabolic*, and it is associated with the two phenomena happening in a muscle, the liberation of energy as movement and heat; in other words, the muscle becomes warmer, and it contracts. Similarly, all living tissues are repaired after exhaustion by the materials brought to them by the blood; they (the tissue elements) perform their appointed function under the action of a stimulus; and the performance of the function involves tear and wear, or the formation of waste matters.

64. Absorption of Waste Matters.—The waste matters arising from the breaking down of tissues, as one of the results of their vital activity, must be removed.

If allowed to accumulate, they become injurious. Consequently they are quickly absorbed and carried to various organs, called the *organs of excretion.* The absorption of waste matters is carried on by two sets of vessels or minute tubes, found in great numbers, and usually forming plexuses or networks with extremely fine meshes. The vessels are (1) the *capillaries*, already mentioned, and (2) another set of vessels termed *lymphatics.* Many waste matters are no doubt at once absorbed by the capillaries, and thus reach at once the blood-stream. The lymphatics originate in fine channels or spaces among the elements of the tissues, such as cells or fibres, and from these spaces delicate vessels carry off the fluid called the *lymph*, which, as already seen, in the first instance comes from the blood. The lymph contains the excess of nutrient matter that came from the blood to nourish the tissues. The portion not used up by the tissues is now the lymph, and to this is added various waste substances that have come from the breaking down of the tissues. The lymph, however, is not thrown out as useless, but is carried, in the first instance, to certain organs called *lymphatic glands.* In these it is submitted to various alterations, and then it is ultimately poured back into the blood by great tubes joining the veins at the root of the neck.

65. Removal of Waste Matters or Excretion.—The blood, thus contaminated with waste substances, either directly by capillary absorption or indirectly by lymphatic absorption, passes to various organs, by which those waste matters are removed. In particular, the lungs carry off the carbonic acid, the chief non-nitrogenous waste product, and the kidneys remove urea, the chief nitrogenous material. Certain matters are also eliminated by the skin, liver, and bowels. Thus, by the function of excretion, the blood is maintained in a state of normal purity, so far as waste products are concerned.

66. Formation of Blood. — We have seen that materials are constantly being removed from the blood for the nourishment of the tissues. To make up for this loss, new materials must be added to it, and these materials are obtained from the food. The food, however, is usually very unlike blood both physically and chemically, and it cannot pass directly into the blood. The food is subjected to certain physical and chemical processes in the important function of digestion, a function carried out in its various stages by many organs, constituting *the organs of digestion.* Thus the food is broken down by the action of the jaws and teeth, it is acted on by the saliva, and it is swallowed and passed into the stomach. There it is acted upon by the gastric juice, and by movement and heat. It then passes into the intestines, and is submitted to the influence of the intestinal juice, the bile, and the pancreatic juice. The result of these actions is to break up the food into a state of fine subdivision, and to render it ultimately soluble. It is then absorbed, and thus reaches the blood. The blood thus receives new supplies of matter from the alimentary canal, it receives oxygen from the air by the lungs, and, as already seen, it receives the lymph. Finally, to the blood are added certain cells from organs termed *blood-glands.* These always contain a tissue, termed adenoid tissue, in which blood-corpuscles are formed. This tissue abounds in the spleen, in the thymus gland, in the walls of the alimentary canal, in the marrow of bone, and in lymphatic glands. Thus the blood is hourly renovated and fitted for purposes of nutrition, and it is driven through the body by the mechanism of the circulation.

67. General Influence of Nervous System.—This part of the body, which includes the brain, spinal cord, nerves, and the organs of sense, is that by which we will, think, feel, perform voluntary movements, and obtain our

knowledge of the world outside our own body. It is a system consisting of many organs, and it controls and regulates all the other organs. As already pointed out, nerves pass to the muscles, and it is by impulses transmitted along these nerves that the muscles are caused to contract. Such nerves are called *motor* nerves. Again, when we prick the tip of the finger with a needle, we irritate nerve fibres, and these carry an impulse to the brain, giving rise to changes there which arouse a *sensation*, or a consciousness of pain, which sensation we refer to the tip of the finger, although it is due to changes in the brain, far removed from the finger. Nerves that carry impulses inwards so as to cause sensations are called *sensory* nerves. There are thus two classes of nerves, of which these may be taken as types. One class, as, for example, the motor, carries impulses outwards from central organs to the periphery or outer parts of the body, and hence is often called *efferent*. The other class carries impulses inwards from the periphery to the central nervous organs, and hence is called *afferent*. Of each class there are several varieties. Thus, of *efferent* nerves we have (1) nerves ending in muscles, causing motion, and hence called *motor* nerves; (2) nerves ending in glands, causing secretion, and hence called *secretory* nerves; and (3) nerves connected with blood-vessels, regulating their calibre, and hence termed *vaso-motor* nerves. Of *afferent* nerves we have (1) nerves causing sensations of touch, pressure, &c., referred chiefly to the skin, and termed nerves of *touch or general sensation;* and (2) nerves from the organs of special sense or *special sensation*, such as (*a*) from the eye, causing vision; (*b*) from the ear, giving rise to sound; (*c*) from the nose, producing sensations of smell; and (*d*) nerves from the tongue, connected with taste. There are also nerves from the skin, which arouse sensations of heat and cold, and pain; from

the muscles that give us information as to position and state of contraction of the muscle (the muscular sense); and from the internal organs, such as the lungs, heart, stomach, &c., that occasionally carry impulses to the brain, and give rise to various sensations, which we locate in or near the organ from which the message comes.

68. Reflex Acts.—Nerves issue from and enter the cord, and issue from and enter the base of the brain, and, as we have seen, they carry afferent and efferent messages. Sometimes these messages are connected with sensation, but sometimes we may be quite unconscious of anything having taken place. For example, we may, by an effort of will, move the right arm or leg, and we know that we have made the movement. These are movements of which we are conscious. But we may see exactly the same movement performed when a person is quite unconscious, as in profound sleep, or in the state called coma, seen in many diseases. The movement, in these circumstances, is excited usually by an irritation of a sensory nerve. We may cause the movement, for example, in a sleeping person by touching the palm of the hand or sole of the foot with a feather. The person has no sensation; he is quite unconscious; he exercises no will-power or volition; and yet the movement is made. Such an action, of which there are many varieties, involving (*a*) an afferent impulse; (*b*) a nerve centre in the cord or brain; and (*c*) an efferent impulse to the muscles involved is known as a *reflex action*. There are many reflex centres in the cord or brain, and they often act automatically in carrying on or modifying functions necessary to life, such as breathing, the state of the circulation in the vessels, and the action of the heart.

69. The Brain and Cord.—The spinal cord is the chief centre for reflex acts. It also contains great strands of nerve fibres passing upwards to the brain and down-

wards to lower parts of the cord. From the sides of the cord issue the spinal nerves, afferent and efferent, as already described. The brain is also connected with reflex acts by means of great masses or ganglia near its base, such as the *medulla* (or *bulb*), the *pons*, and the *proper ganglia of base*, which, arranged in pairs from before backwards, are known as the *corpora striata*, *optic thalami*, and *corpora quadrigemina*. Over all these we find the *cerebrum*, which is concerned in sensation, volition, and intellectual acts. It is especially the *organ of the mind.* Lastly, the lesser brain or *cerebellum* has to do with the co-ordination or regulation of movement—that is to say, it regulates the amount of contraction of each muscle and the order of contraction of the muscles in a group associated for a particular movement. Each organ of the body is thus brought into relation with the central nervous system by afferent nerves, while its operations are more or less under the control of the central nervous system by efferent nerves, and, finally, the central nervous system is itself the seat of operations that are closely associated with all that we understand by the mind.

70. THE MAINTENANCE OF THE ERECT POSTURE.—This will be discussed under ANIMAL MECHANICS.

71. LIFE.—It is impossible to define what life is. Many attempts have been made, and probably the most successful is that of Béclard: 'Life is organisation in action.' The word life suggests *vitality*, and physiologists frequently speak of vital forces, or vital actions. By a vital action is meant simply an action which we cannot at present explain by any chemical or physical laws. The time may come when some phenomena now considered vital may be so explained. These vital phenomena, at present unexplained, may be thus enumerated: (1) *differentiation in growth*, that tendency which an ovum has, by hereditary peculiarities, to develop into a particular

kind of animal, or that tendency which causes the apparently similar cells of the embryo to develop into the various kinds of tissues; (2) *irritability* and *contractility*, properties of muscular fibre; (3) *excitability*, a property of nervous tissue; lastly (4), *mental acts*, such as sensation and volition. Now it must be pointed out that we are acquainted with many of the physical conditions of these phenomena, but not with all. When we know *all* the physical conditions, then we shall probably not speak of them as *vital* phenomena. Even at present no scientific physiologist assumes the existence of a 'vital force' as distinct from other forces, but he contents himself by stating that there are various phenomena which, in the present state of science, he cannot explain by chemical or physical laws.

72. It may be noted, also, that in an individual we find different manifestations of life. Thus we have the life of each independent cell or fibre, the life of each organ, and, lastly, the life of the whole individual, or *somatic* life.

73. Death.—Death is the cessation of all vital phenomena, without the capability of resuscitation. During the whole of the lifetime of an individual there is death in one sense occurring here and there throughout the body. Each tissue is developed, grows to maturity, performs its functions, decays, and dies. Probably no tissue lasts throughout the whole of the somatic life. Thus the cells of the blood are continually changed. Again, hairs, nails, feathers, and teeth have each a certain period of existence, at the termination of which they die and separate from the rest of the body. This may be called *local* death. At last, however, a time comes when the general death of the body takes place. This is what we usually term *death*. It results from failure either of the action of the heart, of the lungs, of the brain, or from death of the blood, as in cases of severe septic poisoning. Death beginning at the

heart (*fainting*) is termed *syncope*, at the brain, *coma*, and at the lungs, *asphyxia*. When the action of the heart becomes weaker and weaker until it ceases to beat, either from feebleness of its walls, or from poisoning by carbonic acid, or from want of oxygen, in consequence of a state of asphyxia, death is said to occur by *asthenia*. After *somatic* death, the tissues may live for a short time, but they gradually die one by one. Muscular irritability disappears, and the muscle stiffens from coagulation of its substance. This rigid state, the 'stiffness of death,' is called *cadaveric rigidity*. After a time the rigidity passes off, the muscles and other tissues become soft, and the body, subjected to the influence of putrefactive organisms, and, finally, to the physical and chemical agencies of nature, is resolved into the elements of which it was at first composed.

Questions.

57, 58. What are the two most evident characteristics of living beings?

58. Explain generally how the human body maintains an equable temperature in a hot summer day and in a cold winter day.

59. Why must a living being be supplied with food?

60. Enumerate the chief waste substances given off by a living being, and mention the channels by which they are given off. How much carbon and nitrogen are given off daily?

61. Show how a human being expends energy. What is the distinction between the internal and the external work of the body?

62. Describe the chief phenomena shown by a living contracting muscle.

63. What are the arrangements in the body by which the 'tear and wear' of the tissues is repaired? What is meant by the terms 'katabolic' and 'anabolic?'

64, 65. How are waste matters absorbed and eliminated?

66. Give a general account of the formation of the blood.

67. What is the distinction between a motor and a sensory nerve?

68. Describe, and give an example of a reflex act.

69. State generally the functions allotted to the chief parts of the central nervous system.

71. What are the chief phenomena of life?

72, 73. What do you understand by death? What is the distinction between somatic and local death?

DIVISION II.—HISTOLOGY.

CHAPTER I.

*THE STRUCTURE AND FUNCTIONS OF THE ELEMENTARY TISSUES.**

The elements of the tissues, in which delicate physiological processes occur, are of such small size that they can only be studied successfully with the aid of a good microscope, capable of magnifying from 20 to 350 diameters linear. They have been variously classified, but, for convenience of description, we will group them under four heads—the molecular, the cellular, the fibrous, and the tubular elements of the tissues.

MOLECULAR ELEMENTS.

74. GENERAL DESCRIPTION.—When we examine under the microscope almost any of the fluids of the body, or a portion of any tissue teased out with needles in water, numerous particles are seen, varying in size from the $\frac{1}{100000}$th to the $\frac{1}{1000}$th of an inch in diameter. These are *molecules*. They consist of minute fragments of other tissues.

75. MOVEMENTS OF MOLECULES.—There are five modes of molecular movement:

(1) The irregular to-and-fro movements known as the *Brownian* movements, observed whenever molecules, whether dead or alive, are suspended in fluids.

* This part is treated in the most elementary manner in the present work.

(2) Movements of molecules in the interior of cells, due to movements of living matter in the cells, called *protoplasm.* These may be seen in the interior of various vegetable cells (such as those of the *Chara*, *Vallisneria*, and *Tradescantia*), but they may also be seen in various animal cells, as, for example, in the salivary cell, with the aid of a powerful lens. These movements are sometimes definite in direction (streaming movements), and are accounted for so far by a circulation of the fluid in which they float; but in other cases, as in the salivary cell, they appear quite irregular, and have more of the character of Brownian movements (fig. 45, *b*).

(3) The to-and-fro and zigzag movements of small living things, of the nature of fungi, known as *Bacteria*, and seen in putrid fluids. These may be due to the action of cilia (see p. 86).

(4) The movements, often in a definite direction, of the molecules of the yolk of the egg after fecundation.

CELLULAR ELEMENTS.

76. General Description of a Cell.—A cell (fig. 40) is a microscopically small body, consisting of a soft substance termed protoplasm, in which there may be imbedded a body called a *nucleus*, *c*, in which there may be a still smaller body, *d*, known as the *nucleolus.* Sometimes the external boundary of the cell may become a hardened stratum, *a*, which is then called the *cell membrane* or *cell wall.* A cell is more than a molecule in a physiological sense; it is the smallest physiological apparatus, to a certain extent complete and independent. It is also a generally received doctrine that

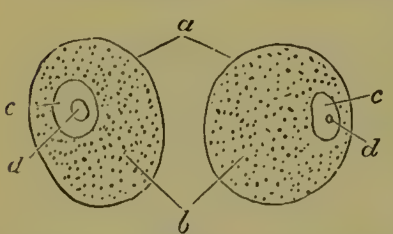


Fig. 40.—Two Cells of round or oval form:

a, border of the cell; *b*, cell body; *c*, *c*, nuclei with nucleoli, *d*, *d*.

all tissues originate in cells. Not infrequently several nuclei may be seen in the same cell or mass of protoplasm, as in fig. 43, *a*, representing a cell or mass of protoplasm from the marrow of bone.

77. Size of Cells.—They vary in size from the $\frac{1}{3000}$th (coloured blood-corpuscle) to the $\frac{1}{400}$th of an inch (the ovum).

78. Form of Cells.—This is extremely variable. The primary form is spherical or oval (fig. 40); but by compression they may become flattened (fig. 41); long and

Fig. 41.—Flattened scaly epithelium Cells from the lining membrane of the human mouth.

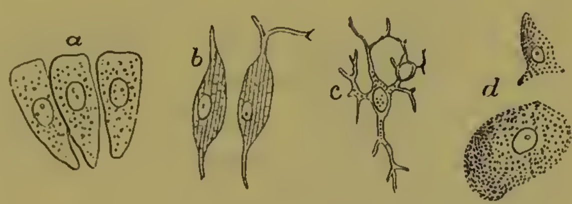


Fig. 42.

a, columnar epithelium; *b*, fusiform connective tissue cells; *c*, stellate cell from lymphatic gland; *d*, protoplasmic cells, with no cell wall.

compressed, as in fig. 42, *a*; fusiform, *b*; and irregular or stellate, *c*.

79. Nature of Protoplasm.—This is a somewhat viscid matter sometimes having albuminous or fatty granules imbedded in it. It seems to be an unstable albuminous matter, insoluble in water, and coagulating at a high or low temperature, or at death. It manifests properties which we term vital, because we cannot account for these properties by any physical processes. It forms the chief part of young cells, but old cells may be filled with other matters, such as fat, pigment, or mineral substances. At an early stage, a cell (physiologically speaking) may consist of nothing more than a little mass of granular

protoplasm, but it usually contains a nucleus (as in fig. 42, *d*).

80. Chemical Constitution of Cells.—The *cell substance*, as already stated, consists of a tough, viscid albuminous substance which coagulates at death, or on being heated up to a certain point. This is about all we know at present regarding the chemistry of protoplasm. In many cells, protoplasm appears to be converted into other substances, such as *enzymes* or ferments (as the pepsin found in the cells of the glandular coat of the stomach), glycogen, a kind of animal starch found in the cells of the liver, and fats. The *nucleus* differs from the cell substance in resisting the action of weak acetic acid, and in having a remarkable affinity for most colouring matters; and according to some authorities, it seems to be modified albuminous matter resembling the substance of elastic tissue. The *nucleolus*, from its refractive properties, is supposed to consist of fat.

81. The Phenomena of Vitality in Cells.—These are: (1) absorption of matter; (2) transformation of the same, either into protoplasm or some material formed by the cell, such as fat; (3) excretion of certain materials which are to be got rid of so far as the cell is concerned; (4) growth, or increase in size and development of parts by the imbibition of new matter; (5) proliferation, or the development of new cells from the old one; and (6) in many, the property of contractility. The latter property, which is one of the most remarkable phenomena of cell life, may be observed in the colourless cells of the blood, and in the cells found in inflamed parts. On carefully watching these cells, they are seen slowly to change their form by throwing out and retracting portions of their body. These movements, from their resemblance to those performed by the little amœba found in ditches, &c., are termed *amœboid*. It is a most interesting fact that

there are many amœboid cells in the living body which wander from the blood-vessels throughout the tissues. During inflammation, colourless blood cells pass from the blood through the walls of the vessels into the surrounding tissues, as seen in fig. 44, and become the cells of '*matter*' or *pus*. This phenomenon, which depends on the property of contractility in these minute cells, not only accounts for

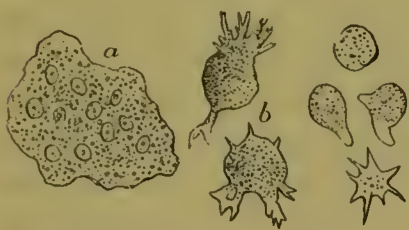


Fig. 43.

a, mass of nucleated protoplasm from marrow of bone ; *b*, lymph-cells, from inflamed eye, showing amœboid processes ; *c*, various forms of colourless cells of the blood.

Fig. 44.—Blood-vessel in Mesentery of Frog during inflammation, showing migration of colourless cells of the blood :

a, cells passing through membranous wall of vessel ; *b*, cells which have passed through ; *c*, coloured cells in stream of blood.

certain of the phenomena of inflammation, but also shows how it is possible that small particles of infecting substances may be taken up by amœboid cells and carried by the latter to distant localities in the body, to the danger or injury of the system. These amœboid cells also devour the minute fungi (*bacteria* and *bacilli*) that cause certain diseases. They have thus a protective function.

82. Conditions necessary for Cell Life.—These are: (1) they must live in a nutritive fluid, from which they can select the various substances necessary to enable them to carry on their functions ; (2) they require a temperature not below zero nor above 145°

F.—a low temperature retarding, while a high temperature favours, all growth; (3) they require room for expansion and an appropriate locality; and (4) the cell itself must be in a healthy condition—that is, the cell wall must not become thickened unduly by mineral matter; the cell substance, or protoplasm, must not be unduly loaded with albuminous, fatty, or mineral substances; and the nucleus in many cases must exist.

83. Reproduction of Cells.—Cells may multiply in three ways: (1) by *budding*, a minute bud may grow from the cell, and this finally drops off and becomes an independent organism; (2) by *simple direct division* of the nucleus, followed by division of the whole cell (sometimes called *karyostenosis*); and by *indirect division*, or *karyokinesis*, in which division of the nucleus is preceded by a number of remarkable forms appearing in it, due to movements of the colourable matter (*chromatin*) existing in the nucleus.

84. Varieties of Cells.—Cells may be divided into: (1) normal isolated cells, floating in a fluid, such as lymph, chyle, and blood-corpuscles; (2) cells with a small amount of intercellular matter, such as epithelial cells; (3) cells embedded in, and intimately connected with, other tissues, such as fat cells, pigment cells, and nerve cells; (4) cells on free membranes which secrete various fluids—secreting or gland cells; (5) cells which, during different periods in the earlier stages of their development, present all the characters and functions of cells, but the tendency of which is to be transformed, or so arranged as to constitute a tissue—cells of transition—such as cartilage, colloid, connective tissue, and embryonic cells; and (6) cells found only in morbid conditions of the tissue, such as pus cells, cancer cells, and tubercle corpuscles.

Epithelium and Endothelium.

85. General Description of Epithelium.—This is a tissue (composed of cells in layers of greater or less thickness) which (1) covers the external and internal surfaces of the body, (2) lines the canals of exit, and (3) clothes numerous closed cavities, such as that between the wall of the chest and the lungs, termed the pleura. The cells found on free surfaces and in ducts are called *epithelial cells*, while those which line the shut cavities have been termed *endothelial cells*. There are different varieties of epithelial cells, such as (1) flat, tesselated, or pavement epithelial cells, from the lining membrane of the mouth (fig. 45, *a*); (2) globular or secreting cells from the ultimate

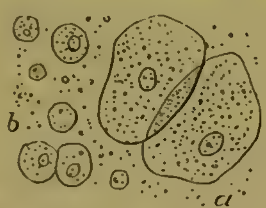


Fig. 45.
Drop of Saliva, showing :
a, pavement or squamous epithelium from mouth ; and *b*, salivary cells.

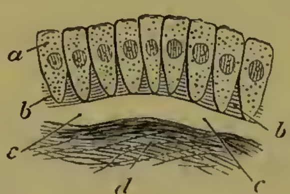


Fig. 46.—Simple coating of Columnar Epithelium on a Mucous Membrane :
a, cells ; *b*, intercellular matter ; *c*, *d*, subcellular tissue.

structure of a gland (fig. 33); (3) columnar cells when they adhere by their sides, as found on the mucous lining of the intestinal canal (fig. 46); and (4) ciliated cells, which may be either globular or columnar in shape, and are distinguished by having small processes or *cilia* at their free border (figs. 47 and 48). The function of epithelium is partly protective and partly for secreting certain matters from the blood.

86. General Description of Endothelium.—Lining the interior of the closed cavities of the body, such as the chest and abdomen, we find a thin membrane usually

called a *serous* membrane. This membrane consists essentially of a single layer of irregularly polygonal nucleated cells (resting on a thin structureless membrane

Fig. 47.—Ciliated Epithelial Cells from the finer bronchial tubes.

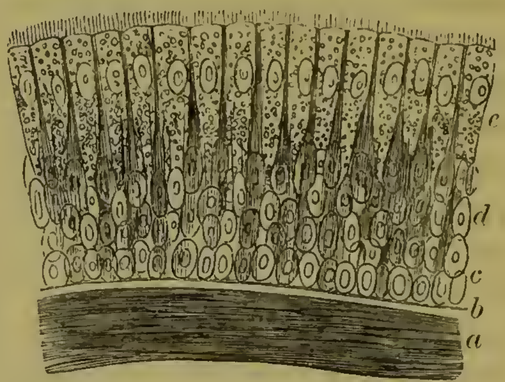


Fig. 48.—Row of Ciliated Epithelium Cells from the trachea of a man :
a, fibrous tissue ; *b*, basement membrane ; *c*, *d*, cells in various stages of development ; *e*, fully formed ciliated cells.

called a *basement* membrane) placed edge to edge (fig. 49, *a*), known as *endothelial* cells. The cavities of the heart and the whole of the blood-vessels are also lined by fusiform cells (fig. 49, *b*, *c*) of a similar kind. *Serous* membranes secrete a thin watery fluid, called *serum* or *serosity*, which lubricates the surface, and permits movement of adjacent parts on each other with little friction.

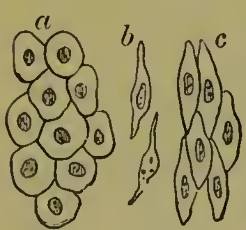


Fig. 49.—Endothelial Cells :
a, from the pleura : *c*, from the lining membrane of a blood-vessel; *b*, similar cells isolated.

87. Ciliary Action.—Ciliated epithelium is found in the air passages, such as the nose, pharynx or throat, trachea or windpipe, and bronchial tubes, in the cavities of the brain and central canal of the spinal marrow, in the middle ear, in the uterus, and in a few other localities. Each cell bears several cilia (figs. 47 and 48), and has a nucleus. The beautiful undulating movement of cilia,

sometimes similar to the appearance of a series of waves travelling along the surface of a field of wheat, at other times such as to convey the idea of running water, can scarcely be described; but it may be readily studied on the gills of the common mussel, or on the tentacles of many small sea-anemones, or other polypes. Ciliary motion persists for some time after the death of the animal, and in the case of cold-blooded animals it may continue for even ten or fifteen days after decapitation. The cause of ciliary movement is unknown. It does not depend directly on the nervous system, nor on a supply of blood, as it will continue in isolated parts for some time after these influences have been removed. An ample supply of oxygen is necessary for ciliary movement. The action of cilia is undoubtedly to excite currents in the fluids in which they are immersed. In many infusoria, locomotion is entirely effected by the action of cilia. In the human body, they assist in the onward movement of mucus. Thus, in the air passages, the action propels mucus upwards towards the opening of the windpipe.

Pigment.

88. General Description.—This is found in the deeper layer of the epidermis, or superficial layer of the skin, and also in the choroid or pigmentary coat of the eye (see Eye). It consists of cells filled with coloured matter placed side by side. There are two distinct forms of these cells: (1) the polygonal (fig. 50, *a*), and (2) the irregular or stellate, as seen in *b*. The colours of the various races of mankind depend on a greater or less amount of pigment in the skin. Such pigment cells are present in the skin of even the

Fig. 50.—Pigment Cells: *a*, from choroid; *b*, from skin of frog.

white races, and they are also found in the investing membrane of the spinal cord, in the membranous part of the internal ear, and in the interior of the nose. In the eye, the pigment absorbs the redundant light; but its uses in the skin and in other parts are unknown. Individuals in whom pigment is wanting are called *Albinos.*

Fat.

89. General Description.—This tissue consists of cells, termed *fat cells*, embedded amongst fine fibres. The cells are round or oval (fig. 51, *a*, *b*), from the $\frac{1}{300}$th to the $\frac{1}{600}$th of an inch in diameter, and each consists of a delicate wall or envelope inclosing a drop of oily matter. When young, they contain a nucleus, but this disappears, or is pressed to the side of the cell (fig. 52, *c*). Frequently small stellate groups of crystals of fatty acids may be seen in the interior (fig. 51, *b*). Fatty matter is called *adipose tissue.* It forms a considerable layer underneath the skin; covers various internal organs, such as the kidneys; is collected in the folds of the serous membranes of the abdominal cavity, termed the mesentery and omentum; is common in the neighbourhood of joints, outside the synovial membrane; and it exists in large quantity in the bones, forming the chief part of the marrow. It is richly supplied with blood-vessels. The uses of fat are: (1) it acts mechanically as a light, soft, elastic packing for the cavities of the body, facilitating motion and diffusing pressure equally;

Fig. 51.—Fat Cells: *a*, imbedded amongst fine fibres; *b*, isolated, and containing small stellate deposits of crystals.

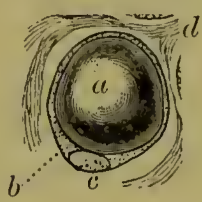


Fig. 52. — Fat Cell (highly magnified): *a*, fat globule; *b*, membranous envelope; *c*, nucleus of cell; *d*, connective tissue.

(2) being a bad conductor of heat, it retains the warmth of the body—hence we find a thick layer of fat (*blubber*) underneath the skins of animals living in arctic regions; and (3) being composed chemically chiefly of carbon and hydrogen, it is oxidised in the tissues, and thus assists in maintaining animal heat. In a well-nourished human being, the amount of fat is said to be about $\frac{1}{20}$th of the weight of the body, but no doubt it fluctuates. Repose of body and mind, much sleep, and rich food favour the development of fat, and in some cases, especially in advanced life, the amount becomes so great as to constitute what we term *obesity*, which cannot be regarded as a healthy condition.

FIBROUS ELEMENTS.

90. A fibre is a solid elongated filament, microscopical in size, and a number of these together constitute a *fibrous tissue*, of which there are four varieties found in the human body. These are: (1) white fibrous tissue; (2) yellow elastic tissue; (3) involuntary or non-striated muscular fibre; and (4) voluntary or striated muscular fibre.

White Fibrous Tissue.

91. General Description.—This is frequently called *connective* tissue, because it binds the various tissues and organs together. It is found underneath and in the skin, between the muscles, in the blood-vessels, and other deep-seated parts, forming sheaths for these structures, and it enters more or less into the constitution of almost every organ. It is also continuous throughout the body. Hence dropsical effusions find their way throughout every part, and suppurations may spread from the spot where the 'matter' or pus was first formed. White fibrous tissue consists of fine filaments (fig. 53, *a*) running in bundles which

often cross each other so as to form spaces or areolæ. Hence, where those spaces are large, it is termed *areolar tissue.* In the meshwork lie fat cells, blood-vessels, &c. In this tissue we also meet with small irregularly formed nucleated cells (fig. 53, *f*, and fig. 54, *a*, *b*, *c*, *d*) called

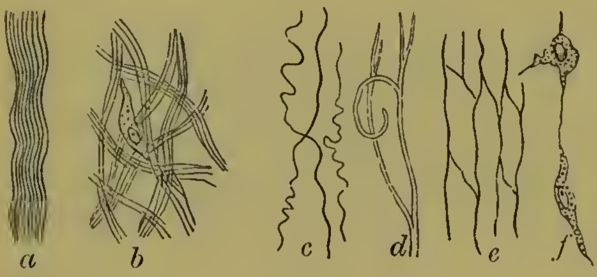


Fig. 53.

a, connective tissue in tendon; *b*, connective tissue from underneath the skin, showing a connective tissue corpuscle; *c*, isolated white fibres; *d*, yellow elastic tissue; *e*, reticulated tissue of elastic fibres; *f*, connective tissue corpuscles, connected by a fine filament.

Fig. 54.

a, *b*, *c*, *d*, various forms of connective tissue corpuscles.

connective tissue corpuscles. This kind of tissue swells up, and becomes transparent and gelatinous on the addition of a drop of weak acetic acid. *Tendon* or sinew is formed of parallel bundles of white fibrous tissue (see fig. 53, *a*).

Yellow Elastic Tissue.

92. General Description.—This is found in the ligaments which join the arches of adjacent vertebræ, in the coats of the larger blood-vessels, in the skin, and in many other structures. It may be conveniently studied in a bit of the *ligamentum nuchæ*, a ligament in the back of the neck of a large quadruped for sustaining its heavy head. It consists of strong, coarse, yellow, elastic fibres (fig. 53, *d*, *e*), which show a tendency to split and to curl up at the extremities. It is not affected by acetic acid. Its chief property is *elasticity*.

Muscular Tissue.

93. The two varieties of fibrous tissue above described act chiefly in a mechanical way in supporting or binding together, or in giving elasticity to various parts. Muscular tissue, in addition, possesses the property of contracting on the application of a stimulus. Of contractile fibrous tissue there are two varieties.

(1) *Involuntary or Non-striated Muscle.*

94. General Description.—This is so termed because its action is not subject to the will—that is, we cannot cause contraction in a part formed of it by willing to do so—and because it does not present the striated appearance characteristic of the other variety. It is found between the coats of the membranous viscera, such as the stomach, intestines, and bladder, in the walls of the air-tubes, ducts of glands, &c. It consists of flattened or ribbon-shaped bands (fig. 55, *a*), which are composed of fusiform or spindle-shaped cells, *b*, sometimes showing, on the addition of acetic acid, an elongated nucleus. It contracts slowly when stimulated.

Fig. 55.
a, portion of a band of involuntary muscular fibre; *b*, isolated cell, showing nucleus.

(2) *Voluntary or Striated Muscle.*

95. General Description.—On examining one of the muscles of the extremities of any animal with the naked eye, we observe that it presents a fibrous appearance. The bundles are called *fasciculi* (fig. 56), inclosed in sheaths

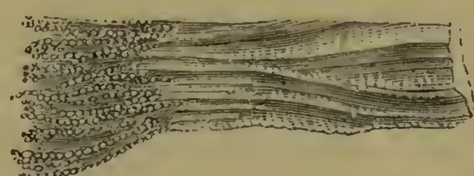


Fig. 56.—Muscular Fasciculus showing its division into fibres.

of white fibrous tissue. A fasciculus consists of a number of *fibres*, of varying size, each of which is inclosed in a structureless sheath or membrane called the *sarcolemma* (fig. 57). A fibre usually shows a tendency to cleave or

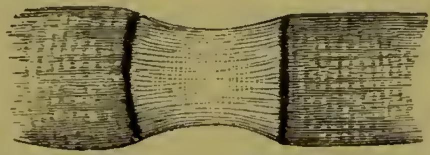


Fig. 57.—Muscular Fibre torn across, and showing the delicate sarcolemma between.

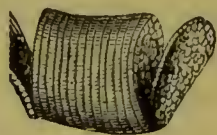


Fig. 58.—Muscular Fibre cleaving at the ends transversely into discs.

split up in two directions, transversely into discs (fig. 58), and longitudinally into still smaller fibres, called *fibrillæ* (fig. 60). Each fibre shows transverse markings or *striæ* (hence the name), as seen in the various figures. This

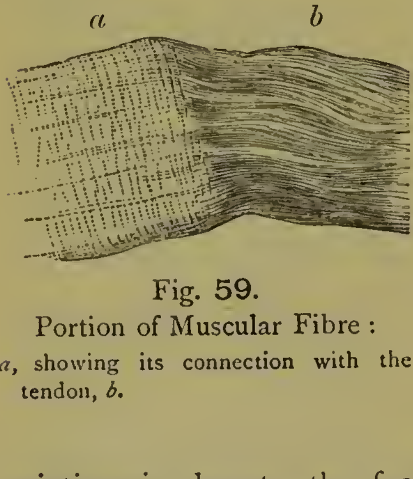


Fig. 59.
Portion of Muscular Fibre :
a, showing its connection with the tendon, *b*.

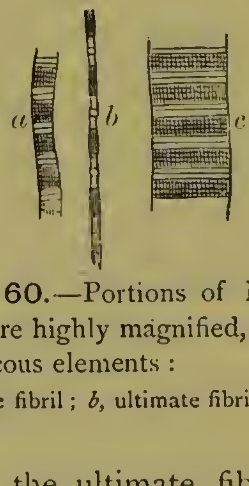


Fig. 60.—Portions of Muscular Fibre highly magnified, showing sarcous elements :
a, large fibril ; *b*, ultimate fibril ; *c*, small fibre.

striation is due to the fact that the ultimate fibril (fig. 60, *b*) is composed of small square-shaped bodies or discs placed end to end, some of which, from the manner in which they are affected by light, appear dark, and others light. The dark discs (which alone are contractile) are termed the *sarcous elements of Bowman*. By studying the figures, the cause of the striated appearance will be understood. In the middle of the clear disc there is a

thin dark line (*Dobie's line*). The length of the fibres is usually about three-quarters of an inch. The fibres at each end of a muscle are attached by white fibrous tissue to the fibrous covering of bone (fig. 59). The *muscle of the heart* shows short square-shaped fibres, faintly striated, and containing a nucleus (fig. 61).

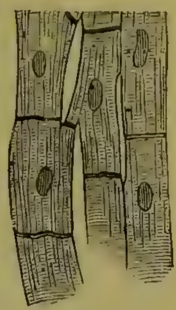


Fig. 61. Muscular Fibres from the Heart.

96. Chemical Constituents of Muscle.—A living muscle in a state of repose contains, within the sarcolemma of each fibre, a semi-fluid substance called *muscle-plasma*, having an alkaline reaction. When this plasma is squeezed out of muscle, it separates into two portions—a fluid termed *muscle serum*, and a solid clot which consists of an albuminous substance called *myosin*. The serum contains albuminous matters; glycogen, a kind of animal starch; nitrogenous matters formed from the decomposition of the muscle during action; salts, chiefly of potassium; water; and gases, chiefly carbonic acid. When a muscle dies, the semi-fluid matter solidifies, and the muscle stiffens. This is called *rigor mortis*. After a muscle has been frequently stimulated to contract, or has been kept for some time in a state of contraction, the plasma becomes *acid* instead of alkaline, from the formation of acid products of decomposition, chiefly an acid similar to that formed in the souring of milk, and termed *sarcolactic acid*.

97. Stimulation of Muscle.—When a muscle is stimulated it contracts. This property of contracting on the application of a stimulus is called *irritability*, a property which has been shown to depend on the inherent structure of the muscle itself, and not upon the nervous system, as was at one time supposed. The stimuli capable of causing a muscle to contract are: (1) the *normal nervous* stimulus, transmitted along a nerve from a nervous centre; (2) *elec-*

trical stimuli, as when it is irritated directly by an interrupted galvanic current, or by a Faradic current; (3) *chemical stimuli*, such as the application of a strong solution of common salt; (4) *thermal stimuli*, such as the momentary application of a hot wire; and (5) *mechanical stimuli*, such as pricking, pinching, &c.

98. Work done by a Muscle.—When a muscle contracts in its normal position, it does a certain amount of *work*, in the form of mechanical movement.

As work cannot be done without expenditure of material, the chemical composition of the muscle alters, so that the constituents which are soluble in water decrease in amount, while those soluble in alcohol increase. This fact clearly indicates that changes take place. When a muscle is stimulated, either directly, or indirectly by stimulating the nerve, it does not contract instantly, but there is a short period of inactivity, followed by the contraction. This period, called *the period of latent stimulation*, has been found to amount to about the $\frac{1}{200}$th part of a second. When a muscle contracts on stimulation, it may do an amount of work, say, in lifting a weight, far in excess of the energy represented by the stimulus. It thus appears that the muscle may be regarded as containing energy stored up, or in a *potential* state; while the function of the normal nerve stimulus is to set free this energy, or to make it *actual* or *kinetic*.

99. Various states of Muscular Contraction.—When a muscle receives a single shock or stimulus of sufficient strength, say, from a galvanic battery, it makes one contraction. If it receives a series of shocks, with sufficient time intervening between the shocks, it contracts and returns to its former size with each shock; but each shock, after a certain time, weakens the muscle, so that it by-and-by will not contract on the application of the stimulus. This state of exhaustion of the muscle is called *muscular fatigue*. If a muscle receives a number of shocks in quick succession, so rapid that it has no time to relax completely between the shocks, it becomes stiff and rigid. The rigid condition thus produced is called *Tetanus*. The contraction of a muscle in the living body is also an

effect of this kind. When a muscle, say, the biceps in the front of the arm, contracts in obedience to a voluntary effort, it does not do so by one nervous impulse being transmitted to it along the nerve from the brain, but by the action of many. One nervous impulse after another follows with great rapidity, and in consequence the muscle gathers itself up and contracts, as in tetanus.

100. THERMIC PHENOMENA OF MUSCLE. — Muscles are hotter during contraction than during a state of rest. This has been ascertained experimentally, and the heat thus produced may be regarded not only as an expression of the chemical changes occurring in the muscle, but also as the appearance, in the form of heat, of a portion of the energy stored up in the muscle.

TUBULAR ELEMENTS.

101. A tube is composed of a wall and contents. In the body we find four varieties of tubes, which will be described in their proper place in discussing the functions with which they are connected. They are (1) air-tubes, in the air-passages and lungs; (2) blood-tubes, in the various kinds of blood-vessels; (3) dental tubules, forming part of the structure of a tooth; and (4) nerve-tubes, usually termed nerve-fibres, the conducting filaments of the nervous system.

There are certain tissues which cannot be conveniently classified under any of the four divisions of molecular, cellular, fibrous, and tubular elements. These are (1) cartilage, or gristle; and (2) bone. Of these we shall now give a brief account.

Cartilage.

102. GENERAL DESCRIPTION.—When in mass, cartilage is opaque, pearly or bluish white, but translucent when cut in thin slices. It is highly and perfectly elastic.

There are two varieties, temporary and permanent. *Temporary* cartilage is seen in the embryo, where the skeleton is cartilaginous, but in due time the cartilage is replaced by bone. *Permanent* cartilage continues as cartilage throughout life. It is seen covering the ends of bones, and entering into the formation of joints, forming an elastic pad which breaks the force of concussions; it forms the cartilages of the ribs (fig. 12), part of the external ear, the nose, the eyelids, the larynx, the windpipe, and the tube leading from the back of the throat to the middle ear, known as the Eustachian tube. When a thin piece of cartilage is examined microscopically, it is seen to consist of a mass of finely granular material known as *matrix*, in which lie imbedded nucleated cells, the *cartilage* cells. When cartilage is boiled for a considerable time, it yields a substance termed *chondrin*.

103. Varieties of Cartilage.—These are: (1) *hyaline*, in which the matrix is clear and transparent, or finely molecular, giving it the appearance of ground-glass (fig. 62, *a*); (2) *white fibro-cartilage*, in which the matrix has become fibrous, the fibres having the characters of those of white fibrous tissue, as seen in the discs between the vertebræ; and (3) *yellow fibro-cartilage*, in which the fibres resemble those of yellow fibrous tissue, resisting the action of acetic acid, and forming a dense matting or felt, in the meshes of which the cells lie (fig. 62, *b*). Yellow fibro-cartilage is sparingly distributed in the body, being found only in certain of the cartilages of the ear and of the larynx.

Fig. 62.—Cartilage: *a*, hyaline, showing cells lying in a slightly granular matrix; *b*, yellow fibrous, showing cells lying in meshwork of coarse fibres.

Bone.

104. GENERAL DESCRIPTION.—Bones are divided by anatomists into the *long* or cylindrical, the *flat* or tabular, and the *short* or irregular. The femur is an example of the first (fig. 19), the parietal of the second (fig. 10), and the astragalus of the third (fig. 21). When any of these bones is sawn across, two kinds of bony tissue are seen—a hard compact part next the surfaces of the bone, and a spongy or *cancellated* part formed of bands and plates in the centre. In the centre of a long bone

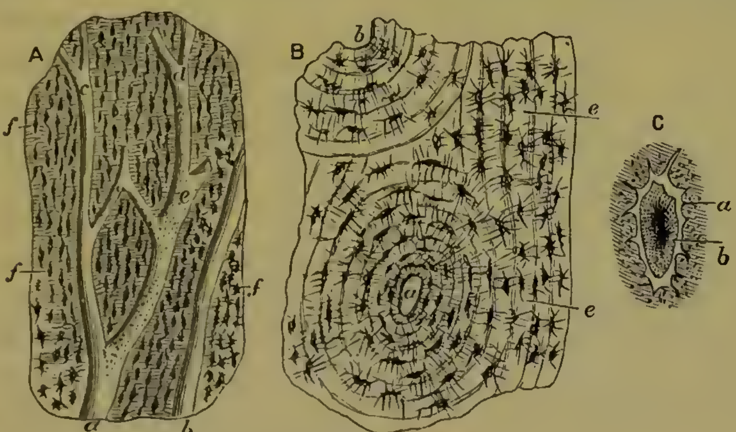


Fig. 63.—Bone :

A, longitudinal section, showing ramifications of Haversian canals, *a*, *c*, *d*, *e*, and *f*, *f*, lacunæ and canaliculi. B, transverse section, showing one complete Haversian system, *a*; part of another, *b*; and an outer lamina, *e*, *e*; *a* is the transverse section of a Haversian canal. C, bone corpuscle in lacuna, highly magnified; *b*, bone corpuscle, a mass of protoplasm; *a*, space between it and bony matter.

there is a canal termed the *medullary canal*, filled with a soft, reddish, pulpy substance called the marrow. The marrow, when examined microscopically, shows fat cells, large nucleated cells (fig. 43, *a*) and blood-corpuscles. In the cancellated tissue, both in the heads of the long bones and in the flat and irregular bones, there is a pulpy matter of a similar character. To examine the microscopic structure of a piece of hard bone, two methods may be followed:

(1) by sawing off thin sections of dried bone, polishing and grinding them into extremely thin slabs on a lapidary's wheel, or on a hone; or (2) by steeping the bone in dilute hydrochloric acid for a few weeks, so as to dissolve out the earthy matter, and leave only the cartilaginous basis, which is so soft as to be readily cut into thin sections with a sharp knife. On examining a *longitudinal* section of bone made by the first method, a series of canals are seen ramifying through the bone (fig. 63, A), called *Haversian canals*, for carrying blood-vessels, &c., and by the side of these canals numerous little dark oblong bodies, from which delicate dark lines pass. On examining a *transverse* section of bone (fig. 63, B), a transverse section of the Haversian canal or canals is seen, *a*, *b*, surrounded by laminæ of bone, in which are imbedded oval dark bodies termed *lacunæ*, from which radiate outwards and inwards numerous very delicate canals known as *canaliculi*. In dead bone, the lacunæ and canaliculi are empty, or filled with bone-dust, but during life each lacuna is occupied by a little mass of protoplasm called a *bone corpuscle* (fig. 63, C), and in the canaliculi fine filaments of protoplasm may be found. These arrangements are evidently intended for the nutrition of the bone. The nutritious matter transudes from the blood-vessels in the Haversian canals, passes through the system of canaliculi, which communicate with these to the first row of lacunæ, and so on throughout not only the entire *Haversian system*, as it is termed, which surrounds the canal, *a*, but through adjacent systems, such as *b*.

105. Growth of a Bone.—Every bone is formed either in membrane or cartilage, and the process is called *ossification*. It is a process too obscure and difficult to be treated of in this elementary work, but there are certain practical facts regarding the growth of a bone which may be briefly described. In the early embryonic state, a long bone, say, the femur, is entirely

cartilaginous; but at a certain definite period a deposit of earthy matter takes place in the shaft, which gradually extends towards each extremity, so that, about the eighth month of fœtal life, the shaft is completely ossified, A, but both ends are cartilaginous. At birth, a second deposit of earthy matter (termed an *ossific centre*) has taken place in the lower end, B. After birth, the bone grows in length and thickness. At the age of one year, a second ossific centre makes its appearance in the head of the bone, C. We have now three ossified portions, the shaft, the lower extremity, and the upper extremity. Between the ossified shaft and the partially ossified extremities, the bone is still cartilaginous, and it is here that growth in length chiefly takes place. A study of fig. 64 will show the subsequent steps by which the bone becomes entirely ossified. The ossified portions separate from the shaft are termed *epiphyses*. After a bone has become completely ossified, it ceases to grow in length, but it may increase in thickness by the development of new bony material on the outside, beneath the fibrous covering of the bone termed the *periosteum*. Each bone is richly supplied with blood by the vessels of the periosteum, and by a special nutrient vessel which usually penetrates the bone. These facts show (1) that bone is not a dead inert mass, as many may suppose, but that it is a living, growing tissue, especially in early life; and (2) that in early life, before the long bones of the lower extremities

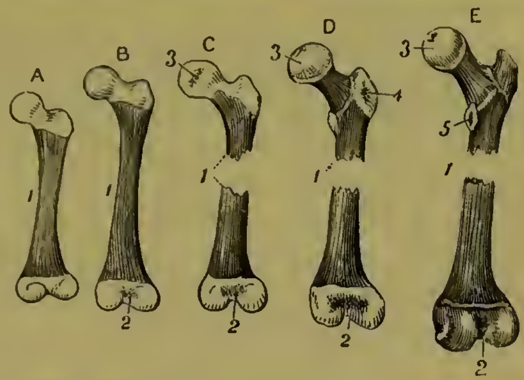


Fig. 64.—Ossification of the Femur:

A, femur of a fœtus about eight months; the shaft is osseous; both ends are cartilaginous. B, femur of a child at birth, showing a nucleus of earthy matter, 2, in the lower end. C, femur of a child of about a year old, showing a nucleus in the articular head, 3. D, femur of the fifth or sixth year, where ossification has extended from the shaft into the nucleus in the head, and a nucleus has appeared in the great trochanter, 4. E, femur about the age of puberty, showing more complete ossification, and a nucleus in lesser trochanter, 5.

have completely ossified by union of the epiphyses with the shaft, there is danger of bending the bones at the cartilaginous portions and in the shaft by allowing the child to walk at too early a period.

106. CHEMICAL CONSTITUTION OF BONE.—Bone consists of an earthy and of an animal part. The animal part is a soft flexible substance, obtained, as above mentioned, by steeping a bone in diluted hydrochloric acid. On boiling this, it yields gelatin. The earthy part, got by burning bones, consists largely of tribasic phosphate of lime, carbonate of lime, fluoride of calcium, phosphate of magnesia, and chloride of sodium. In old age, the bones become brittle, from the large amount of earthy salts they then contain.

QUESTIONS.

75. Describe the different kinds of molecular movements.
76. Draw the form of a cell, and describe its various parts.
79. What is protoplasm?
81. How may we know that a cell is alive?
82. What conditions are favourable to cell growth?
83. What are the various ways in which cells multiply?
85. Enumerate the different kinds of epithelium.
87. Describe ciliary motion. Where are cilia found in the body?
88. Where are pigment cells found?
89. Describe the structure and uses of fat.
91. Describe white fibrous tissue. Where is it found?
94. Where do you find non-striated muscular fibre?
95. Describe the structure of striated muscle.
96. What do you know of the chemical composition of muscle?
97. How may a muscle be called into action?
99. What is cramp or tetanus? What conditions fatigue a muscle?
102. Describe the varieties of cartilage found in the body.
104. Describe the structure of bone.
105. How does a bone grow in length and in thickness?
106. How could you obtain the organic part of a bone? How could you obtain the ash? What is the composition of the ash?

DIVISION III.—SPECIAL PHYSIOLOGY.

CHAPTER I.

THE BLOOD.

107. General Characters.—The blood is the most important and most abundant fluid in the body. With the exception of a few tissues, such as the centre of the cornea of the eye, the nails, and the hair, it pervades every part of the body, as may be shown in the case of the skin by puncturing any part of it with a needle. The total quantity is estimated at about one-eighth of the weight of the body, or about 20 pounds in a man of average size. Its colour is red, but it varies from a bright scarlet in the arteries to a dark purple in the veins. When, however, a minute drop is examined under the microscope, it is seen to be made up of, first, a clear colourless fluid; and, secondly, of a multitude of small solid bodies or *corpuscles*, which float in the plasma. This plasma, called *liquor sanguinis*, is composed of water richly charged with materials derived (through the chyme) from the food—namely, albumin, globulins, various fats, &c. The greater part of the blood—about 70 per cent.—is made up of water. In 100 parts of blood by weight, we find 60 to 65 of plasma and 30 to 40 of corpuscles.

108. Microscopical Appearance of Blood. — The great majority of the corpuscles are of a yellowish-red colour, and, by their enormous number, impart a red hue to the blood; while a few are white or colourless. The

red corpuscles in man have a diameter of about $\frac{1}{3300}$th of an inch, being about $\frac{1}{4}$th of that fraction in thickness; in form they are circular biconcave discs (fig. 65, *a*), and in freshly drawn blood they arrange themselves, by contact of their flattened surfaces, into rolls like piles of coins (fig. 65, *e*). The colourless corpuscles are larger, globular or irregular in form, and present a granulated appearance (fig. 65, *d*). It is well known that these are little masses of living protoplasm, capable of spontaneous movement, and that they are identical with the corpuscles found in purulent

Fig. 65.—Blood-corpuscles:

a, two coloured corpuscles showing shadowed appearance in the centre, indicating biconcave form; *b*, corpuscle seen edgeways; *c*, slightly oval corpuscle; *d*, colourless corpuscle; *e*, coloured corpuscles in rouleaux.

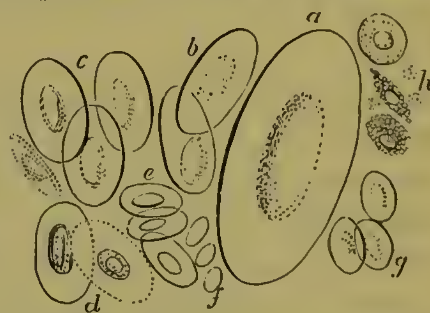


Fig. 66. — Blood-corpuscles of various Animals magnified to the same scale:

a, from proteus; *b*, salamander; *c*, frog; *d*, frog after addition of acetic acid, showing nucleus; *e*, bird; *f*, camel; *g*, fish; *h*, crab or other invertebrate animal.

matter or pus. In all classes of animals the colourless corpuscles are alike; but the form of the coloured corpuscles varies, being oval in fishes, reptiles, and birds (fig. 66). In all mammals they are circular, with the exception of the camels and llamas, where they are oval (fig. 66, *f*). The red corpuscles are more numerous than the white, being in the proportion of about 400 to 1. In a cube $\frac{1}{25}$th of an inch on the side, there may be in normal blood about 5,000,000 red corpuscles.

109. Blood-corpuscles of Various Animals.—The coloured blood-corpuscles of all mammals have no nucleus,

swell up and become globular on the addition of water, and almost entirely disappear in weak acetic acid. The coloured corpuscles of birds, reptiles, and fishes have a nucleus which is readily seen on the addition of water or acetic acid. Acetic acid renders the body of the colourless corpuscle clear and transparent, and reveals the existence of a peculiarly shaped nucleus, as if several small granules or nodules adhered together.

110. CHEMICAL CONSTITUTION OF PLASMA. — The plasma is alkaline, yellowish in colour, and its specific gravity is about 1026 to 1029. In 100 parts of plasma, we find of water, 90·2, and of solids, 9·7. The composition of the solids is approximately as follows: Proteids: (1) fibrin, ·4; and (2) other proteids, chiefly serum albumin, 7·8; extractives, ·56; and inorganic salts, ·85. Thus plasma contains 10 per cent. of solids, of which 8 per cent. are proteids. The specific gravity of pure *blood* is as high as 1050.

111. COAGULATION OR CLOTTING OF THE BLOOD. — Shortly after its removal from the body, the blood begins to thicken or coagulate, and soon separates into two distinct parts, one of them being a dark-red jelly or *clot*, which is the heavier of the two, and sinks; while the other is a clear, straw-coloured fluid, called the *serum*, which covers the clot. This depends on the formation of a substance called *fibrin*, which forms a meshwork of fine molecular fibres, entangling the corpuscles. When a coagulum appears, fibrin is produced by the action of an enzyme, or ferment-like body, on a proteid substance called *fibrinogen*. Fibrinogen belongs to the class of proteids called *globulins*, distinguished from albumins by being insoluble in water, while they are soluble in a weak solution of common salt. It is probable that the ferment decomposes fibrinogen into two parts: (1) another globulin that remains in solution, and (2) the insoluble body fibrin. The ferment itself is also a peculiar kind of proteid, and is believed to

come from the colourless corpuscles. Coagulation may be thus represented :

$$\text{Blood}\left\{\begin{array}{l}\text{Plasma}\left\{\begin{array}{l}\text{Serum}\\ \text{Fibrin}\end{array}\right.\\ \text{Corpuscles}\end{array}\right\}\ \text{Clot.}$$

Clotting is hastened by (1) a temperature a little above that of the body, (2) contact with foreign matter, and (3) agitation; and it is hindered or prevented by (1) cold, (2) contact of living walls of blood-vessels, and (3) addition of solutions of sulphate of magnesia or sulphate of soda.

112. Other Chemical Substances in Blood.—These are small quantities of sugar, cholesterin, soaps, and fats; traces of urea, uric acid, kreatin, &c. The most abundant salt is chloride of sodium, or common salt, being about 90 per cent. of the total saline matters.

113. Chemical Composition of Corpuscles.—One hundred parts of *red* blood-corpuscles contain of water 68·8 parts, and of solids about 31 parts—the solids contain 30·3 of organic matter, and about ·8 of inorganic. The chief organic substance is hæmoglobin, the pigment of the blood. One hundred parts of *dried* corpuscles contain of proteid ·5 to 1·2 parts, of hæmoglobin 8·6 to 9·4, of lecithin (a fatty nitrogenous matter containing phosphorus) ·18, and a trace of cholesterin. Hæmoglobin is of special importance, because, by uniting with oxygen to form oxy-hæmoglobin, it acts as the oxygen carrier in respiration.

Questions.

107, 111. Describe the appearance of blood to the naked eye immediately after it has been shed, and half an hour thereafter.

108. What is the appearance under the microscope of a drop of human blood? Compare the red blood-corpuscles of a man with those of a camel, a bird, a reptile, and a fish.

110. Give a short account of the chemical composition of the blood.

111. What conditions hinder, and what conditions quicken, the clotting of blood?

113. What substances are found in a red blood-corpuscle?

CHAPTER II.

CIRCULATION OF THE BLOOD.

114. The blood is in constant motion in a definite direction during life, and the motion is known as the *circulation.* Its true course was discovered by Harvey, about 1620. The organs of circulation are the heart, arteries, veins, and capillaries. We will first briefly describe the structure of these, and then treat of the mechanism of the circulation.

115. THE STRUCTURE OF THE BLOOD-VESSELS.—Of these there are three kinds—capillaries, arteries, and veins. The

Fig. 67.—Capillaries of various size :

a, capillary much magnified and acted on by nitrate of silver, so as to show that it is made up of flattened cells ; *b*, a smaller vessel showing the same ; *c*, a small artery or vein showing transverse and longitudinal nuclei ; *d*, ultimate capillary from *pia mater* of sheep's brain.

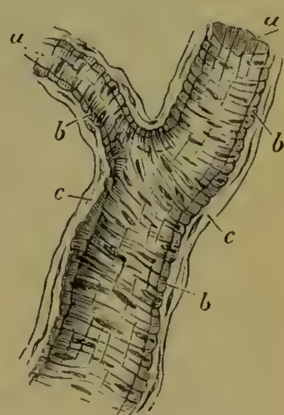


Fig. 68.—An Artery of intermediate size :

a, *a*, openings of branches and position of lining of vessel ; *b*, *b*, *b*, muscular coat showing transverse nuclei ; *c*, *c*, coat of connective tissue.

capillaries are delicate tubes, about the diameter of a blood-corpuscle (fig. 67, *d*), apparently formed of transparent membrane, with nuclei imbedded here and there in the wall ; but they are composed of flattened cells, adhering edge to edge

(fig. 67, *a*, *b*). In vessels somewhat larger, we find outside of the lining (which is composed of *endothelial* cells, see p. 86) a delicate, transparent, and fragile membrane, which tends to curl upon itself, from its elasticity. It is perforated by numerous small holes. Outside of this there is a layer of muscular fibre-cells arranged longitudinally and transversely, the nuclei of which are seen after the addition of acetic acid (fig. 68). This constitutes what is usually termed the *muscular coat*. In large arteries, we find outside of, and intimately connected with, the muscular coat a thick layer of yellow elastic tissue, which gives great elasticity to these vessels; and most externally there is a layer of connective tissue. As the vessels are traced towards their capillary terminations, they gradually lose their connective tissue and elastic coats. In *small arteries*, called *arterioles*, the wall is composed entirely of two layers of longitudinal and circular muscular fibre-cells, lined by endothelial cells, and in the ultimate capillary these fibre-cells have disappeared, and there is only a thin wall formed of endothelial cells, as above described. Veins differ from arteries chiefly in the comparative thinness of their coats. It is important to bear in mind that the predominant feature of the larger arteries is *elasticity*, while that of the smaller is *contractility*. The ultimate capillaries are also independently contractile.

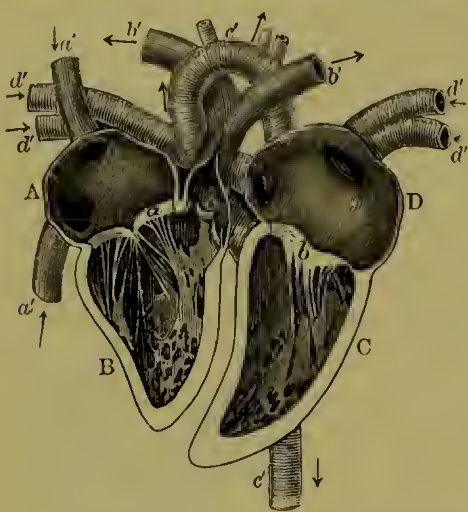


Fig. 69.—Diagram of Heart halved and laid open:

A, B, C, D, as in fig. 70. *a*, part of tricuspid valve; *b*, part of mitral; *c*, semilunars at base of pulmonary artery. *a'*, *a'*, inferior and superior venæ cavæ entering A; *b'*, *b'*, pulmonary arteries proceeding from B; *c'*, *c'*, aorta proceeding from C; *d'*, *d'*, pulmonary veins entering D.

116. The Position and Structure of the Heart.—This organ is situated in the thorax or chest, between the two lungs, and, together with portions of the great vessels

which convey blood to and from it, is inclosed in a membranous bag, the *pericardium*. It is a hollow organ, having muscular walls. The following anatomical points may be clearly made out on the heart of an ox or of a sheep, a demonstration of which will teach far more than we can hope to explain in these pages. It is divided (fig. 69) by a septum into a right and left half, each of which is again subdivided by a transverse partition into two compartments, communicating with each other, named the *auricle*, A, D, and *ventricle*, B, C. The apex of the heart may be felt in the living man between the cartilages of the fifth and sixth ribs, a little below, and to the inner side of, the left nipple.

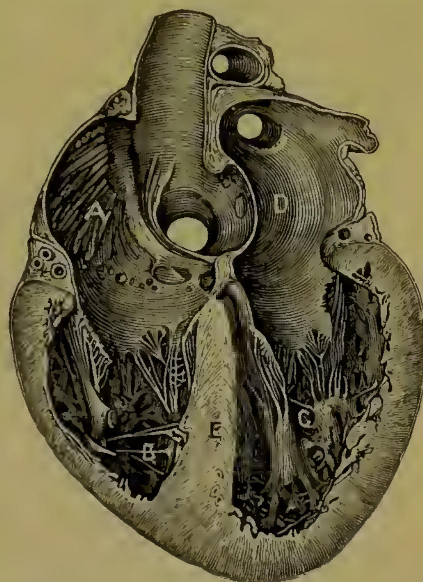


Fig. 70.— Section of the Human Heart :

A, right auricle ; B, right ventricle ; C, left ventricle ; D, left auricle ; E, partition between the two ventricles. Between the auricles and ventricles on right and left, the tricuspid and mitral valves with their cords and muscular papillæ are shown.

The heart is a double organ, composed of a right and left part, each consisting of an auricle and ventricle. These are named, in the order in which the blood passes through the heart, *right auricle*, A ; *right ventricle*, B ; *left auricle*, D ; and *left ventricle*, C. Into the right auricle, blood passes by the following openings ; (1) from the head, neck, and upper extremities by the *superior vena cava, a′;* from the lower part of the body by the *inferior vena cava*, *a*, and from the wall of the heart itself by numerous small veins. The blood passes from the right auricle to the right ventricle through an

opening in the partition between the auricle and ventricle known as the *right auriculo-ventricular opening*, which is guarded by a valve called the *tricuspid valve* (fig. 69, *a*). From the right ventricle the blood is sent to the lungs through the *pulmonary artery*, *b'*, and it is returned from the lungs to the left auricle by four *pulmonary veins*, *d'*, and from thence to the left ventricle through an opening in the septum between the auricle and ventricle, called the *left auriculo-ventricular opening* (*b*), where we find a valve corresponding to the tricuspid on the right side, but composed of two flaps instead of three, and hence called the *mitral* valve, from its fancied resemblance to the upper part of a bishop's mitre. At, or a little above, the orifices of the pulmonary artery and of the aorta, we find valves which, from their shape, are termed the *semilunar valves*. See figs. 70 and 71, and description.

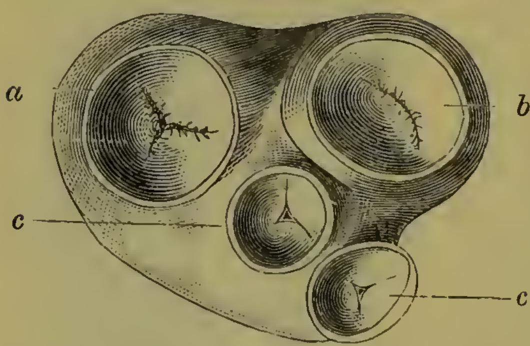


Fig. 71.—Section through the Heart at the level of the valves.

The *tricuspid*, *a*, is seen in the upper left corner, the *mitral*, *b*, in the right, and below, the two *semilunar* valves, *c*, *c*, at the orifices of the aorta and pulmonary artery.

The substance of the heart is composed of a spiral arrangement of seven layers of muscular fibre. When the ventricles contract, which they do simultaneously, the blood is propelled from them with a sort of spiral motion, as if it were wrung out of the heart. The simultaneous contraction of the two auricles is much more gentle.

117. General Description of the Course of the Circulation.—This may be studied with the aid of a diagram (fig. 72), which is equally applicable for all other mammals as well as for man and for birds. The parts of fig. 72 in black represent structures filled with impure or

venous blood, while the clear or white parts represent structures in which pure oxygenated *arterial* blood occurs. Observe in fig. 69 the four cavities, A, B, C, D, of which the heart is composed. Two of these cavities, A and D, are for the purpose of receiving the blood as it flows into the heart, and are termed the *auricles;* while the two cavities, B and C, are for the purpose of propelling the blood through the lungs and the rest of the body respectively, and are termed the *ventricles.* The vessels that transport blood into the auricles are termed *veins;* and the vessels through which blood is driven onwards from the ventricles are known as *arteries.* The diagram (fig. 72) further shows that what we commonly term the heart may be regarded as *two distinct hearts* in apposition with each other; one, black in the figure, which is called the *right*, or *venous*, or *pulmonary* heart; and the other, white, called the *left*, or *arterial*, or *systemic* heart, the last name having been given to it because the blood is sent from it to the general system; just as the right heart is termed pulmonary because it sends blood to the lungs.

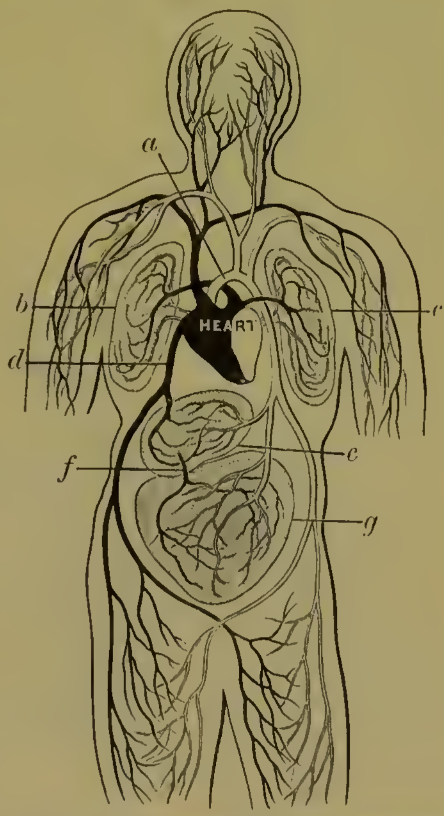


Fig. 72.—Diagram of the Circulation.
The arteries are shown white, and the veins black. *a*, aorta; *b*, right, and *c*, left lung; *d*, inferior vena cava; *e*, liver; *f*, portal vein; *g*, digestive organs.

118. We shall now trace the course of the blood as indicated by the arrows in the diagram (fig. 73), commencing with the right auricle. The right auricle, contracting upon the venous or impure blood which has been returned from the body, and with which we suppose it to be filled, drives its contents onwards into the right ventricle, through an opening between these two cavities, called the right auriculo-ventricular opening, which is guarded by a valve, named *tricuspid*, from its being composed of three pointed membranous expansions, which almost entirely

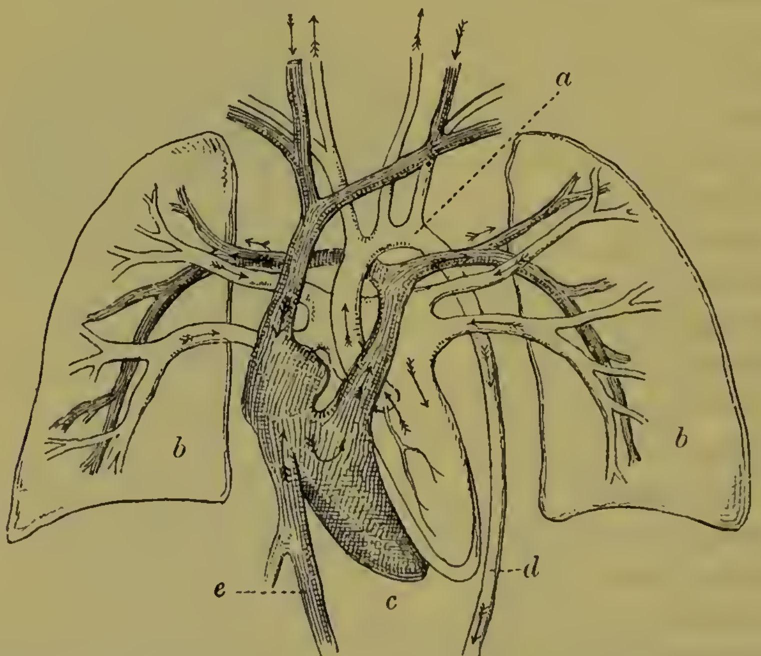


Fig. 73.—Scheme of Course of Blood through Heart and Lungs: *a*, arch of aorta; *b*, *b*, lungs; *c*, heart; *d*, aorta; *e*, inferior vena cava.

prevents the regurgitation or reflux of the blood from the ventricle into the auricle (figs. 70 and 71). The ventricle being now filled, contracts; and, as the blood cannot return to the auricle, it is driven along the vessel (shaded in fig. 73), the *pulmonary artery*, which conveys the blood to the lungs. At its commencement it is guarded by valves,

termed, from their shape, the semilunar pulmonary valves, which entirely prevent the blood that has been once propelled into the pulmonary artery from re-entering the ventricle (figs. 71 and 74). The pulmonary artery gradually divides into smaller and smaller branches, ultimately merging into capillaries. In the capillaries, freely distributed over the external surface of all the air-cells (of which the lung is mainly composed), the venous blood is brought into contact with atmospheric air, gives off its carbonic acid gas (its principal impurity), and absorbs oxygen, by which processes it is converted into pure or arterial blood. The capillaries, in which the blood is arterialised, gradually unite to form minute veins, which, again, join to form larger vessels, until finally the blood is collected into four vessels, known as *pulmonary veins* (two from each lung), discharging their contents into the left auricle. The blood, now fitted for the various purposes of nutrition, enters the left auricle, which, by its contraction, propels it into the left ventricle, through the left auriculo-ventricular opening. This opening, like the corresponding one in the right heart, is guarded by a valve, from its form termed the *mitral* valve, which entirely prevents the reflux of the blood. The left ventricle contracts, and drives its contents into the large artery (fig. 73, *a*), the aorta—the great trunk—which, by means of its various branches, supplies every portion of the body with pure arterial blood. See figs. 75 and 76, and description.

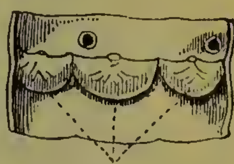


Fig. 74.—Semilunar Valves of Aorta and Pulmonary Artery.

119. From the aorta and its various subdividing branches, many of which are seen in fig. 75, the blood passes into the *capillaries*, which occur in every part of the system (fig. 77). In these capillaries it undergoes important changes, which may be considered as almost the reverse of those

occurring in the pulmonary capillaries; it parts with its oxygen, becomes charged with carbonic acid, and, as it leaves the capillaries and enters the minute veins formed by their union, presents all the characters of venous blood. The veins gradually unite till they form two large trunks, termed the superior and inferior *venæ cavæ* (fig. 75, 1, 4), which pour

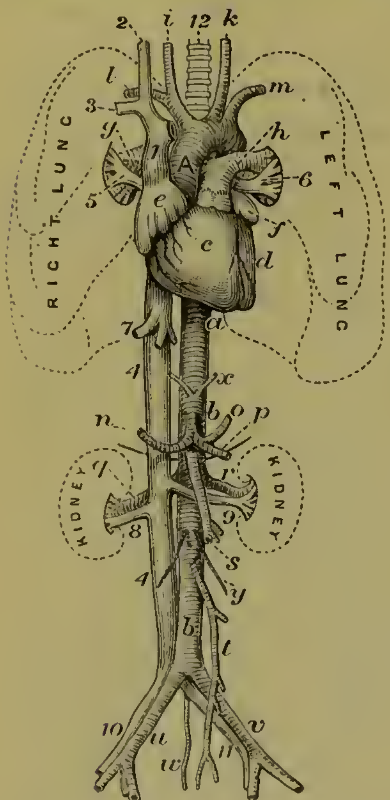


Fig. 75.—Diagram of the Aorta, with its principal Branches:

A, ascending part of the arch of the aorta; *a*, thoracic aorta; *bb*, abdominal aorta; *c*, *d*, right and left ventricles of heart; *e*, *f*, right and left auricles of heart; *g*, *h*, right and left pulmonary arteries; *i*, *k*, right and left common carotid arteries; *l*, *m*, right and left subclavian arteries; *n*, hepatic artery; *o*, gastric artery; *p*, splenic artery; *q*, *r*, right and left renal arteries; *s*, *t*, superior and inferior mesenteric arteries; *u*, *v*, right and left common iliac arteries; *w*, middle sacral artery; *x*, phrenic arteries; *y*, spermatic arteries.

1, superior vena cava; 2, right internal jugular vein; 3, right subclavian vein (the left is removed to show the arch of the aorta); 4, inferior vena cava; 5, 6, right and left pulmonary veins; 7, hepatic veins; 8, 9, right and left renal veins; 10, 11, right and left iliac veins; 12, trachea.

their contents into the right auricle—the point from which we started. We thus perceive that there is a complete double circulation; that there is a lesser circulation effected by the blood in its passage from the right to the left heart through the lungs, and that there is a great circulation effected by that fluid in its passage from the left heart, through the system generally, to the right heart.

120. Influence of Elasticity of the Great Arteries, and of the Contractile Coats of the

Small Arteries, on the Circulation.—But although the heart is the chief organ for propelling the blood, there are other forces at work. When the left ventricle contracts, blood is propelled into the aorta, which, however, contains blood at the time. This blood is pushed forwards, and the aorta dilates. When the propulsive power has ceased, the aorta, being a very elastic tube, recovers its original calibre. In doing so, it assists in forcing the blood onwards. Thus, by successive portions of the larger arteries acting in the same manner, dilating with the impulse, and regaining their size by elasticity, the original mechanical force of the heart, which throws blood into the aorta in a series of successive jets, is converted into a uniform wave-like movement, sent along the walls of the arteries, which we term the pulse. The *pulse*, which beats about seventy times per minute, is the change produced in the diameter and length of an artery when it receives the wave of blood. The effect of the elasticity of the vessels is to convert the sudden spasmodic action of the contraction of the ventricle into a continuous uniform movement. Hence in the capillaries, as seen in the web of a frog's

Fig. 76.—The Arterial System: *a*, temporals; *b*, carotid; *c*, artery of arm; *d*, aorta; *e*, kidney; *f*, artery of thigh (femoral).

foot, there is no jet-like movement, but the blood flows onward in one continuous stream. The smaller arteries, *arterioles*, possess a thick muscular coat, and this coat is kept in a state of partial contraction, by which their calibre is diminished. The effect of this is to keep the arterial system, as it were, overfull, because the blood thrown into the aorta and great arteries by each stroke of the heart does not at once rush through the capillaries into the veins. Suppose a long, elastic india-rubber tube, with a stop-cock at one end and a force-pump at the other. If we drive water by the pump in at one end, the water might rush out at the other end to the same amount. This would be the case if the stop-cock were wide open; but if we partially turned off the stop-cock, then the water would not run out so quickly, and the tube would become distended. The same thing occurs in the arteries during life. The great arteries are always overfull, and their walls are distended. Consequently, there is always a considerable *pressure* in the great arteries. This pressure is shown if an artery is punctured. The blood then comes out with a spurt or jet. This pressure is called *blood pressure*. It is greatest in the large arteries, and becomes less and less as we pass onwards. It is smaller in the capillaries, and still smaller in the veins.

Fig. 77.
Termination of artery (A) in capillaries (C), and those in vein (V).

It is also important to notice that the force of the elasticity of the great vessels always comes into play during the intervals between the heart-beats. Thus, in the first place, the blood is driven onwards by the force of the heart-beat, or, in other words, by the contraction of the left

ventricle. This force also partially distends the arteries, and these rebound during the relaxation of the ventricle, and the elastic rebound or recoil forces the blood onwards while the ventricle is distending.

We must carefully distinguish between the velocity of the pulse-wave and the velocity of the current of the blood. Suppose a river flowing slowly along in one direction. We might, by a dip of an oar, cause a wave to travel on the water in the same direction as the stream was flowing; but the rate at which the wave travelled would be much faster than the rate of flow of the river. The same happens in the case we are considering. The *pulse-wave* travels along the walls of the arteries much faster than the blood-stream. The blood-stream is fastest in the great vessels, and slowest in the capillaries. While the blood passes along the veins the stream again flows faster as these become wider and wider. In addition to this, the blood is sucked onwards towards the heart by the action of the auricle, and by the inspiratory movements.

The tissues also exert a feeble attractive influence on the blood, drawing it forwards; and consequently we find that, wherever we have activity of growth in any part of the body, there is a determination of blood to that part. We see this in the congestion which precedes the annual growth of a stag's horn.

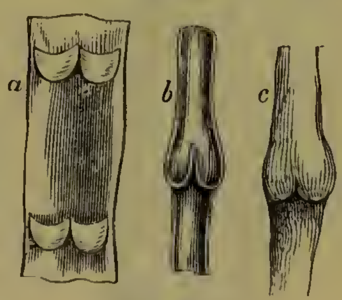


Fig. 78.
Valves in Veins:
a, vein slit open, showing semilunar valves; *b*, side view, showing the valves closed; *c*, vein with swelling at valves.

121. Action of the Veins.—After the blood has passed through the capillaries into the veins, the power of the heart has reached a minimum. The blood is now forced along the veins to the heart, chiefly by the pressure of the muscles. Many of the veins are provided with valves, which are so arranged

as to allow the blood to flow only towards the heart; and, consequently, when a muscle contracts and presses on a vein, the blood is propelled forwards (figs. 78, 79.)

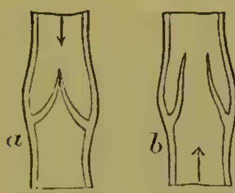


Fig. 79.—Mode of Action of Valve: *a*, shut; *b*, open. No backward flow possible in *a*.

122. Influence of Respiration.—Lastly, the movements of respiration affect the circulation; inspiration, by increasing the flow of blood along the great vessels to the heart; while expiration has the contrary effect. By inspiration the cavity of the chest is increased, and pressure is removed from the surfaces of the heart and great veins. Hence the pressure on these surfaces becomes less than atmospheric pressure, and as atmospheric pressure acts on the veins *outside the chest*, the blood is driven onwards to the heart. In other words, it is sucked or aspirated. Expiration has the contrary effect.

Fig. 80. — The Veins of Arm, as in the operation of bleeding.

The bandage above the elbow prevents the blood flowing up the veins. These are seen distended. By working the fingers round the rod (the representative of the barber's pole), the blood is driven more and more to the distended veins. A vein is then opened at the bend of the elbow.

a, *a*, valve.

123. Rhythmic Movements of the Heart.—The auricles contract synchronously—that is, at the same time, and pour their blood into the ventricles. When these are full, they also contract synchronously, the right sending blood to the lungs, and the left to the body.

124. Conditions affecting the Pulse.—Muscular

exertion, if violent, quickens the pulse. It is more frequent in the erect than in the sitting position, and quicker then than in the recumbent posture. Sex appears to exercise an influence. The natural pulse in the adult male varies between 60 and 70 pulsations per minute, that of the female being on an average about 10 beats more. In the newly born infant it is from 130 to 140; in old age, from 50 to 60; but occasionally in old age it is much more rapid. The pulse is quicker in the morning than in the evening; it reaches its maximum about noon, and its minimum soon after midnight. The pulse is quickened by excitement, and sometimes slowed by fear. It is quickened in most diseases, especially so in those of a febrile character; but it is slowed usually in jaundice and in cases of compression of the brain.

125. Circulation in the Capillaries.—Few sights are more beautiful than the circulation of the blood in the web of a frog's foot. The blood flows in a continuous stream, the coloured corpuscles in the centre of the vessels, while the colourless (much fewer in number) may be observed travelling more slowly, especially after irritation of the part, at the side of the current, and occasionally clinging to the wall of the vessel. It has been estimated that the blood flows in the capillaries at the rate of about 1 inch per minute. In an artery it runs probably about 15 inches per second, and slower in a vein. The arrangement of the capillaries of the skin are seen in fig. 81. Each tissue and organ has its characteristic arrangement of these small vessels.

Fig. 81.—Arrangement of the Capillary Loops in the skin.

Questions.

114. Who was the discoverer of the circulation of the blood?
115. Describe the structure (*a*) of a capillary, (*b*) of a small artery, and (*c*) of a vein.
116. Describe the position of the heart in the thorax, mentioning the vessels connected with it at its base. What structures are seen in the right ventricle and in the left ventricle? Describe and draw the semilunar valves at the orifice of the aorta.
117. Describe the course of the circulation, beginning at the right auricle. What do you mean by the pulmonary circulation?
118. When the ventricle contracts, how is the blood prevented from passing back into the auricle, on the right side?

118, 119. During what time of the heart's action are all the cavities filling with blood?

120. What is the influence of the elastic coat in the greater arteries on the circulation? Show how it is that during life we may regard the arteries as always overfull. What is meant by blood-pressure? Why is it high in the arteries? How does the contractile coat of the smaller arteries affect the circulation?
121. Draw a diagram showing the action of the valves in veins.
122. How does inspiration affect the circulation?
124. What conditions influence the rate of the pulse?
125. Describe the circulation in the capillaries.

CHAPTER III.

THE ALIMENTARY SYSTEM.

126. General View.—This function is a complex process. To keep up the integrity and vigour of the body, food must be procured, chewed or masticated, mixed with saliva, swallowed, digested in the stomach, the nutritious material absorbed by special organs in the bowels, called villi, and from these carried to various glands, where it is elaborated into blood. The blood is then conveyed through the body, giving up to the tissues what they require for nourishment, and carrying away materials resulting from

their decay. Thus rendered impure, the blood must have the noxious materials removed. For this purpose, several organs, such as the lungs, the liver, the skin, the kidneys, and the lower bowel, are set apart. Thus the blood is constantly replenished with nutritious matters, and constantly being purified, so as to fit it for supplying each individual cell of the body with exactly the material it requires. Bone selects earthy salts, muscle needs albumin, the nervous system requires fatty matter, and so on.

The general arrangement of the alimentary canal is

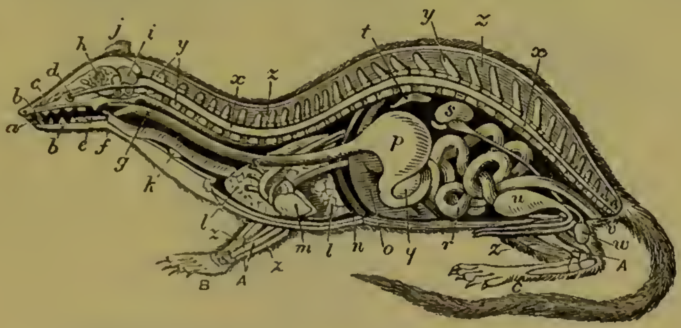


Fig. 82.—Diagram of a Vertebrate Animal :

a, mouth ; *b*, *b*, teeth ; *c*, olfactory nerve ; *d*, optic nerve ; *e*, palate ; *f*, epiglottis ; *g*, œsophagus, or gullet ; *h*, cerebrum, or great brain ; *i*, cerebellum, or lesser brain ; *j*, external ear ; *k*, trachea, or windpipe ; *l*, lung ; *m*, heart ; *n*, diaphragm ; *o*, liver ; *p*, stomach ; *q*, pancreas ; *r*, small intestine ; *s*, kidney ; *t*, spleen ; *u*, bladder ; *v*, anus ; *w*, testicle ; *x*, *x*, spinal cord ; *y*, *y*, processes of vertebræ ; *z*, muscle. A, A, bones of legs ; B, foot ; C, hind-leg.

seen in fig. 82, representing an ideal longitudinal section of a vertebrate animal ; fig. 29, p. 36, should also be studied.

The process of nutrition is complex only in the higher animals. In the amœba (fig. 83), a little animal which is nothing more than a mass of jelly-like living material, containing a nucleus, *nc*, and often small contractile bags or vacuoles, *vc*, we find no trace of organs, and nutrition is carried on by any part of the body. A little fragment of nutritious matter may be surrounded by the protoplasm of the body of the animal, and by it is also converted into

protoplasm, *vc*. But as we ascend in the scale of animal life, one organ after another is added, such as a digestive sac, glands for secretions to act on the food, a special fluid —the blood, an organ and vessels for circulating this fluid; and so on, till we come to the higher animals, where we find a complex system in operation.

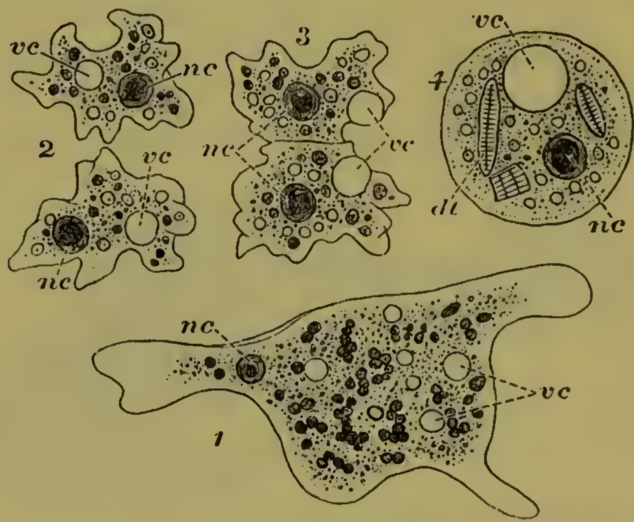


Fig. 83.—Amœba.

1, amœba with blunt processes, nucleus, *nc*; contractile vacuoles, *vc*; food vacuoles and granules. 2, two daughter amœbæ. 3, amœba in process of dividing. 4, encysted phase, with inclosed diatoms, &c.

Question.

126. Describe generally the process of nutrition. Give an account of nutrition, as carried on by an amœba.

FOOD OR ALIMENT.

127. Necessity for Food.—A living being is always in a state of change. His skin gives off water, either in the form of sweat or as an invisible vapour; his kidneys also separate water, the water in both cases containing salts and other matters in solution; and his lungs are always exhaling, not only watery vapour, but the gas known as carbonic acid, as may be readily shown by breathing into lime-water,

which soon assumes a milky appearance, in consequence of the formation of carbonate of lime. Moreover, as has already been shown, the body, which has an almost constant temperature of about 98·4° F., is always giving off heat, so that if a man were surrounded by ice, part of the ice would be melted, and the amount of heat might be estimated by the weight of water produced. The production of heat indicates chemical changes in the body, accompanied by waste of material. In addition, there is a constant expenditure of energy in carrying on the internal work of the body, or in doing the daily outside work of life. If this condition of things were to go on indefinitely, the weight of the body would gradually diminish, and the person would become weaker and weaker. To retain the body in an efficient state both as regards matter and energy, it must be supplied with *atmospheric air*, *water*, and *food*. We have placed these in the order of their importance.

128. Physiological Importance of the Air.—The atmosphere consists of a mechanical mixture of 4 parts of nitrogen and 1 part of oxygen. In 100 volumes of air (say 100 cubic inches), there are 20·81 of oxygen and 79·19 of nitrogen. By weight, in 100 parts, there are 23·01 of oxygen and 76·99 of nitrogen. In addition, the air always contains a small amount of carbonic acid (about 4 parts in 10,000 parts), a small quantity of an element called argon, a variable but minute trace of ammonia, traces of nitric acid, and frequently in towns traces of sulphurous acid and sulphuretted hydrogen. Finally, it contains variable quantities of aqueous vapour. The constituent of greatest importance in the economy of the body is oxygen. Without this gas, life cannot be prolonged for more than a few minutes. Consequently, there are special arrangements for introducing it into the body. This constitutes part of the process of respiration.

129. PHYSIOLOGICAL IMPORTANCE OF WATER.—When we recollect that water is present in every tissue of the body, and especially in those tissues which are of the greatest importance to life, such as brain or muscle, we see at once the importance of a due supply of this fluid. The presence of *water* is a condition of all vital activity. It is the solvent by which substances are brought into close contact with each other, and it is the medium in which all those molecular processes occur on which life depends. It is remarkable, too, that it is in a constant state of transition in the body, and as it is continually being given off, it must be replenished. Hence all animals introduce into the body water, either as such, or combined with the food.

130. CLASSIFICATIONS OF FOOD.—Various classifications of the food of man have been proposed; but the following is simple and practical: The *aqueous;* the *albuminous;* the *fatty*, *oily*, or *oleaginous;* the *starchy* and *saccharine;* the *gelatinous;* and the *saline* groups. All our daily food is referable to one or more of these classes. The *aqueous* group includes not only water, but all fluids (except oils) used as drink, and it must be recollected that so-called solid foods contain a large percentage of water. The *albuminous* group is typified by the white of egg, and includes the gluten of flour and the chief constituents of flesh and cheese. The albuminous foods chiefly nourish the muscles, but they contribute, along with fat or oil, to almost every tissue. The *fatty* group includes all animal and vegetable fats or oils. The *starchy* and *saccharine* group contains all the varieties of sugar, starch, dextrin, and gum. The starches and sugars belong to the group of *carbo-hydrates* (see p. 57). This group is largely used by the muscles, and to some extent they form fat. The *gelatinous* group is represented by cow-heel, isinglass, and such-like substances, yielding jellies and soups that stiffen on cooling;

while the *saline* group includes mineral matters, especially common salt, and phosphates of the alkalies, and of lime, &c. The saline or mineral matters form bone, tooth, &c., and they are found in variable proportions in almost every fluid and solid in the body. It must be remembered, however, that a *mixture* of all of these constituents of food is essential to the formation of a nutritious diet, and, moreover, that there must always be a certain amount of *sapidity* or *flavour* in the food. We should turn with disgust from a mess consisting of these constituents, even in proper proportions, if it were not palatable or tasty. The best example of a natural food is milk. It contains water, albumin in the form of casein (the chief constituent of cheese), fat in the form of cream (or butter), sugar, and various salts. Hence it is nature's food for all young animals of the mammalian group.

131. CONDITIONS DETERMINING THE QUANTITY OF FOOD.—These are: (1) the amount of oxygen in the atmosphere and the temperature; (2) the amount of mental and bodily exertion and (3) the activity of growth. Exercise and exposure to cold sharpen the appetite, and thus lead to more food being taken. It is also well known that dwellers in the arctic regions not only eat a great deal of food, but of that kind which, by oxidation by the oxygen of the air, is heat-producing—namely, oleaginous matter. On the other hand, the inhabitants of the tropics eat sparingly, and chiefly of products rich in carbo-hydrates, such as starch, sugar, &c. In a temperate clime, something between the two extremes is found to be most conducive to health.

132. FOOD AND WORK.—It is evident that the amount of food must have some relation to the work done by the individual. Hard work means expenditure of matter and energy, and these must be supplied by food. The following table shows the quantities, in ounces avoirdupois, of

the different materials of dry food required under different circumstances:

Nature of the Diet.	Nitrogenous matter.	Fat.	Carbo-hydrates.	Salts.	Total.
Bare subsistence diet	2·33	0·84	11·69	...	14·86
Adult in full health, with moderate exercise.......	4·215	1·397	18·960	0·714	25·286
Active labourer, not over-worked....................	5·41	2·41	17·92	0·68	26·42
Hard-working labourer, navvy........................	5·64	2·34	20·41	0·68	29·07

Add to each of these from 60 to 80 ounces of water, taken either alone or as part of the food in a succulent or cooked state. Thus it would appear that in ordinary life, and with a fair amount of labour to perform, a healthy adult requires daily about 28 or 30 ounces of dry nutritious food, along with about 70 ounces of water.

133. Different kinds of Food.—The nutritious value of different articles of diet depends (1) on their digestibility; and (2) on the amount they contain of the proximate constituents which are required for nourishing the body. There are great differences in the percentage composition of food, as may be seen in the following table:

TABLE SHOWING THE PERCENTAGE COMPOSITION OF VARIOUS ARTICLES OF FOOD.

Nature of Food.	Water.	Albumin.	Starch.	Sugar.	Fats.	Salts.
Bread	37	8·1	47·4	3·6	1·6	2·3
Wheat flour.............	15	10·8	66·3	4·2	2·0	1·7
Oatmeal.................	15	12·6	58·4	5·4	5·6	3·0
Rice.....	13	6·3	79·1	0·4	0·7	0·5
Potatoes.................	75	2·1	18·8	3·2	0·2	0·7
Peas.......................	15	23·0	55·4	2·0	2·1	2·5
New milk......	86	4·1	...	5·2	3·9	0·8
Cheese	36·6	33·5	...	...	24·3	5·4
Beef.......................	51	14·8	...	...	29·8	4·4
Pork.......................	39	9·8	...	...	48·9	2·3
Poultry...................	74	21·0	...	...	3·8	1·2
White fish................	78	18·1	...	...	2·9	1·0
Egg.......................	74	14·0	...	...	10·5	1·5

A glance at the preceding table will also show that the habit of combining different articles of diet, such as bread and butter, beef and potatoes, chicken and ham, &c. is physiologically correct. It also shows that oatmeal porridge and milk make a highly nutritious diet.

Questions.

127. Show why food is necessary.
128. What is the composition of pure atmospheric air?
129. Why must water be taken daily into the body?
130. Classify foods. Give an example of each class. Why is a mixture of food-constituents necessary for a healthy diet?
131. What circumstances determine the quantity and quality of a diet?
133. Show why oatmeal porridge, beef and bread, bread and cheese, and milk and bread form food diets.

We shall now describe the steps in the process of digestion.

134. Mastication.—Mastication is effected in the cavity of the mouth by means of the teeth, which fit into sockets in the upper and lower jawbones (figs. 10 and 11, and fig. 84). The upper jaw is immovable, or only movable with the entire head; but the lower jaw, with its teeth, is capable of moving upwards, downwards, backwards, forwards, and laterally, by means of the powerful muscles of mastication. It is by the varied movements of the lower teeth against the upper,

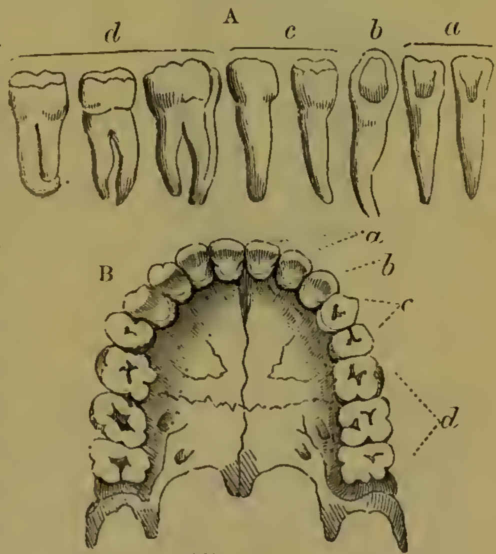


Fig. 84.

A, the separate human teeth as they occur in the half-jaw of the adult; B, the human teeth *in situ* in the upper jaw; *a*, *a*, incisors; *b*, *b*, canines; *c*, *c*, premolars; *d*, *d*, true molars.

through the action of these muscles, that food is broken down or masticated. The *tongue* also, moved by its muscles, gathers together the food from below the dental arches, and crushes it against the palate. In the adult there are 32 teeth, 16 in each jaw, and 8 on each side. There are from before backwards, beginning in the middle line of the jaw, 2 incisors or cutting teeth on each side; 1 canine or eye-tooth, for seizing; 2 premolars or bicuspids, for tearing; and 3 molars or grinders, for crushing and breaking up the food (fig. 84, A). The body and greater

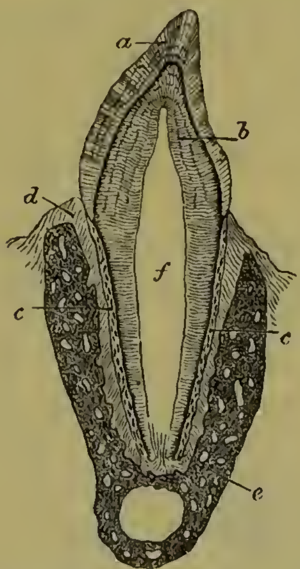


Fig. 85.—Vertical Section through a Tooth lodged in its socket :

a, enamel ; *b*, dentine ; *c*, crusta petrosa or cement ; *d*, lining of the cavity in the gum ; *e*, bony socket in gum ; *f*, pulp-cavity.

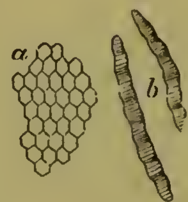


Fig. 86.

a, surface of enamel prisms ; *b*, two prisms isolated.

bulk of each tooth consists of substance called *dentine* (fig. 85, *b*), composed of branching tubes; the top or crown is covered by a cap of *enamel*, a very hard substance, made of small hexagonal prisms (fig. 85, *a*, and fig. 86), and the fang or root is protected by a layer of a material resem-

bling bone, called *crusta petrosa* or cement (fig. 85, *c*). In the centre of each tooth there is a cavity containing pulpy matter, in which are nerves and blood-vessels (fig. 85, *f*).

135. INSALIVATION. — Insalivation is effected by the admixture with the triturated food of the secretions of three pairs of salivary glands (the parotids, the submaxillaries, and the sub-linguals) (fig. 32), and of the mucus secreted by numerous small glands beneath the lining of the cheeks, gums, and tongue, called *buccal* glands. The salivary glands belong to the class of what are called *racemose* glands, consisting of numerous ducts which divide and subdivide until they become extremely small. At the extremities of the ducts there are a series of little pouches or follicles, lined by the cells which secrete from the blood materials which the cells manufacture into saliva (fig. 33). Certain nerve fibres terminate in the cells, or send fine filaments amongst them (fig. 87). The common *saliva* formed by the combined secretion of these various secreting organs is a colourless, slightly turbid, viscid, inodorous, and tasteless fluid. In the normal state its reaction is alkaline. Saliva does not contain more than five or six parts of solid constituents to 995 or 994 parts of water. The saliva formed by the sub-lingual gland is richest in solids (2·75 per cent.). Submaxillary saliva contains about 2·2 per cent., and parotid saliva only ·4 per cent. The substances in saliva are *mucin* (as in mucus), *ptyalin* (the enzyme), a globulin proteid, sulphocyanide of potassium, common salt (sodium chloride), and traces of sodium carbonate, calcium phosphate, &c. The daily quantity of saliva secreted by an

Fig. 87.—Nerves terminating in a cluster of Cells in a salivary gland:
a, nerve; *b*, *b*, *b*, cells; *c*, nucleus; *d*, small swellings or nerve tubes.

adult man is estimated at about 48 ounces, but the activity of the salivary glands is dependent upon various influences and conditions. Thus, movement of the lower jaw, as in masticating, speaking, or singing, increases the secretion —acrid and aromatic substances and hard dry food also increase it. It is also under the influence of mental states, emotions, and desires, through the nervous system, for the sight of a feast or tempting dish may make one's 'mouth water,' while fear is known to parch the mouth.

The uses of the saliva in reference to digestion are partly mechanical and partly chemical. The chemical use of the saliva is, by the action of its enzyme, *ptyalin*, to convert the starchy portions of the food into a form of sugar (maltose), and thus to promote its absorption. It also moistens the mouth, and so assists in speech and swallowing. The public speaker cannot articulate when his mouth becomes dry, and we cannot swallow a perfectly dry powder. When saliva is swallowed with starchy food, the action goes on for 15 to 25 minutes, until *free* acid appears in the contents of the stomach. An acid (hydrochloric) is poured into the stomach at the beginning of digestion in that organ, but the acid first formed combines with proteids of the food. After these compounds have been formed, free acid persists, and immediately destroys ptyalin, arresting any further conversion of starch into maltose.

Questions.

134. Enumerate the teeth in the jaw of an adult man. Make a drawing of a tooth, showing the position of the tissues of which it is composed.
135. Describe the position of the glands that secrete saliva. What is the chemical composition of mixed saliva? What are the uses of saliva?

136. Deglutition.—Deglutition is the act by which the food is transferred from the mouth to the stomach.

The mouth leads into a cavity called the *pharynx* (see figs. 31 and 34). Between it and the mouth is the soft *palate*, which is a movable muscular partition that separates the two cavities during mastication. As soon, however, as the latter act is accomplished, and the bolus is pressed backwards by the tongue, the soft palate is drawn upwards and backwards, so as to prevent the food passing into the nose. The vocal cords (see VOICE) are brought close together, and the opening of the windpipe is closed by a lid called the *epiglottis*. The bolus or pellet of food having arrived near the œsophagus or gullet (which is continuous inferiorly and posteriorly with the pharynx), is driven into it by the action of certain muscles, which almost surround the pharynx, and are termed its constrictor muscles. All voluntary action ceases as soon as the food is pressed backwards by the tongue into the pharynx. It is impossible to recall the pellet, and it is carried on (even without our cognisance) into the stomach. This involuntary mechanism is called a *reflex* action. All reflex mechanisms require a stimulus to call the parts into action. The stimulus in this case is the contact of the food with the back of the tongue and throat. The reader will find that he cannot perform the action of swallowing if nothing, not even saliva, is in his mouth.

The food is carried down the œsophagus or gullet to the stomach by a peculiar vermicular contraction of the muscular fibres of the former, well seen when a horse is drinking water. This kind of movement is called a *peristaltic* action.

137. DIGESTION IN THE STOMACH.—The whole of the alimentary canal below the diaphragm, or muscular partition which separates the cavity of the chest from that of the abdomen or belly (fig. 29, O, p. 36), possesses the following points in common, in relation to structure. The stomach, the small intestine, and the large intestine, are

all lined by *mucous membrane*, have a muscular coat of involuntary muscular fibres, consisting of two sets of fibres—namely, circular fibres internally, which surround the tube or viscus after the manner of a series of rings, and longitudinal fibres externally, running in the same direction as the intestine itself—and are invested with a smooth, glossy, *serous membrane*, which, while it retains the viscera in their proper position, also permits their necessary movements with a minimum of friction.

The human stomach is an elongated curved pouch (fig. 35, p. 44), lying immediately below the diaphragm. It is very dilatable and contractile, and its function is to retain the food until it is duly acted upon and dissolved by the gastric juice, which is secreted by glands lying in its inner coat, and then to transmit it, in a semi-fluid state, into the first part of the small intestine, called the duodenum. Its average capacity is about five pints.

138. The Mucous Membrane of Stomach. — The mucous membrane, or lining coat of the stomach, is thick and soft, and lies in irregular folds, in consequence of the contraction of the muscular coat, unless when the organ is distended with food. On opening the stomach, and stretching it so as to remove the appearance of folds, we perceive numerous very shallow pits or depressions. The rest of the thickness is chiefly made up of minute tubes (fig. 88), running vertically towards the surface of the stomach, and secreting the gastric juice from the blood in the capillaries or minute blood-vessels which abound in the mucous membrane. These tubes are lined throughout with columnar epithelial cells. Near the cardiac end of the stomach, the gastric glands show two kinds of secreting cells: (1) the gland is lined by columnar epithelial cells, called the central or *principal cells;* and (2) outside of these, bulging from the wall of the gland, we find large granular cells, called *parietal cells* (fig. 88, B). The glands

near the pylorus have only principal cells (fig. 88, A; see description of fig.). It is supposed that the central cells secrete pepsin, while the parietal form hydrochloric acid. The zymogen in the peptic cells is called *pepsinogen.* Pepsin is different from the enzyme that curdles milk, known as the *milk-curdling ferment.* Pepsin differs from all other enzymes in acting only in an acid medium.

139. CHANGES IN STOMACH. — When food is introduced into the stomach, it is subjected to three actions—first, to heat, the temperature of the stomach being, during digestion, about 99° F.; second, to a slow movement round and round, so as to bring the food into contact with the lining; and, third, to the chemical action of a special fluid —the gastric juice.

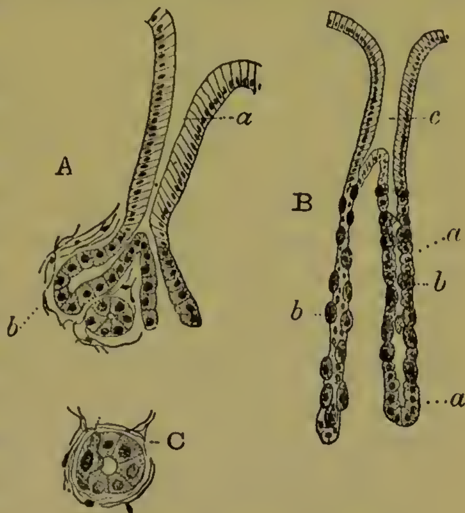


Fig. 88.—Gastric Glands: A, from pyloric end of stomach: *a*, clear columnar cells of mouth of gland; *b*, end of gland, with more granular cells. B, from cardiac end: *a*, principal cells; *b*, *b*, parietal cells; *c*, mouth of cardiac gland. C, transverse section of gland.

The food, on entering the stomach, first passes into the cardiac end, thence along the greater curvature from left to right to the pyloric end, and from thence along the lesser curvature from right to left.

140. The changes in the mucous membrane are: The inner surface of the healthy fasting stomach is of a paler pink than after the introduction of food, which causes the exudation of a pure, colourless, viscid fluid, having a well-marked acid reaction. This fluid, which is the *gastric juice*, collects in drops, which trickle down the walls, and mix with the food. Its two essential elements are: (1) a

free acid, which is usually hydrochloric alone, and occasionally a mixture of hydrochloric and lactic acids; and (2) an enzyme called *pepsin*.

141. Chemical Nature of Gastric Juice.—The gastric juice is highly acid, from the presence of free hydrochloric acid. The formation of free acid, from the blood and lymph bathing the parietal cells, both of which fluids are alkaline, may be accounted for by the interaction of chloride of calcium with the hydrogen-sodium-phosphate of the blood. The result of the action is phosphate of calcium, sodium chloride, and *free* hydrochloric acid. One hundred parts of gastric juice collected from the human stomach gave, of water, 99·44, organic matter, chiefly pepsin, ·32, of hydrochloric acid, ·02, and very small quantities of various salts, chiefly common salt. The gastric juice of the dog is richer in all its constituents, containing 1·7 per cent. of pepsin and ·3 of hydrochloric acid. Probably the average amount of hydrochloric acid is ·2 per cent.

142. Action of Gastric Juice.—The uses of this fluid are not only to dissolve but also to modify the nitrogenous elements of the food (such as albumin, fibrin, casein, and, in short, all animal food except fat), converting them into new substances, termed *peptones*, which, although they coincide in their chemical composition, and in many of their physical properties, with the substances from which they are derived, differ essentially from them in their more ready solubility in water, in their power of rapidly dialysing, or passing through animal membranes, as well as in various chemical relations. The formation of peptone is one of hydration; that is to say, the proteid is caused to take up water. Peptones are not at once formed; intermediate bodies called *proteoses* being produced, and there is also the formation of a body called acid-albumin or *syntonin*. All peptones are more soluble and diffusible substances than the proteids, from which they were formed.

The gastric juice exerts no action on the fats and the carbo-hydrates (sugar, starch) (see p. 57). If the fats are in animal cells, the walls of which are formed of albumin, the walls are dissolved, and the contents set free. The cellulose walls of vegetable cells are usually unaffected.

143. CASE OF ALEXIS ST MARTIN.—The process of gastric digestion was studied in 1838 by Dr Beaumont and others in the remarkable case of Alexis St Martin, a man who had a gunshot injury in 1822, which left a permanent opening through the abdominal wall into his stomach, guarded by a little valve of mucous membrane. Through this opening, the mucous membrane could be seen, the temperature ascertained, and numerous experiments made as to the digestibility of various kinds of food.

144. ABSORPTION IN THE STOMACH.—What becomes of the matters that are thoroughly dissolved in the stomach? The albuminates, &c. which are converted into peptones, are for the most part taken up by the blood-vessels of the stomach, and by another set of vessels in the bowel, called the *lacteals*. At the moment of their absorption, however, peptones are converted into serum-albumin, the chief proteid of the blood, by the action of the living cells in and on the walls of the stomach and the coats of the vessels. The rapidity with which aqueous solutions of iodide of potassium, the alkaline carbonates, lactates, citrates, &c. pass into the blood, and thence into the urine, saliva, &c. shows that the absorption of fluids must take place very shortly after they are swallowed; and there is little doubt that the blood-vessels (capillaries) of the stomach constitute the principal channel through which fluids pass out of the intestinal tract into the blood.

145. TIME REQUIRED FOR DIGESTION.—There can be no doubt that the stomach is admirably adapted for the digestion of the food introduced into it, because it has been shown by numerous experiments that digestion will go on

in gastric juice out of the stomach, but that it requires three or four times longer a period than when performed by the stomach itself. In the stomach, in most individuals, rice and tripe are digested in one hour ; eggs, salmon, and venison in one and a half hours ; tapioca, liver, and fish in two hours ; lamb, pork, and turkey in two and a half hours ; beef, mutton, and fowl in three and a half hours ; and veal in four hours. There are, however, considerable differences in various individuals, or even in the same individual at different times.

146. CONDITIONS FAVOURABLE FOR GOOD DIGESTION.—These are : (1) a temperature in the stomach itself of about 99° to 100° F. ; (2) constant movement of the walls of the stomach, so as to bring the food thoroughly into contact with the mucous membrane and gastric juice ; (3) the removal from time to time of such portions as have been fully digested ; (4) a state of softness and minute division of the food ; (5) the quantity of food taken—the stomach should be moderately filled, but not distended ; (6) the time which has elapsed since the last meal, which should always be long enough for the food of one meal to have completely left the stomach before another meal is introduced ; (7) the amount of exercise previous and subsequent to a meal, gentle exercise being favourable, while over-exertion is injurious ; (8) the state of the mind, tranquillity of temper favouring good digestion ; (9) the general state of the bodily health, the stomach of an invalid not being usually so fit for digestion as that of a person in robust health ; and (10) the period of life, digestion being more active in the young than in the old.

QUESTIONS.

136. Describe the process of swallowing.
138. Describe the parts seen in a section through the coats of the stomach.
140. What is the appearance of the lining membrane of the stomach before and after taking food ?
141. What are the constituents of the gastric juice ?
146. What are the conditions favourable to healthy gastric digestion ?

147. DIGESTION IN THE BOWELS.—After the food, by digestion in the stomach, has been converted into a semi-fluid mass called the *chyme*, it passes into the intestine

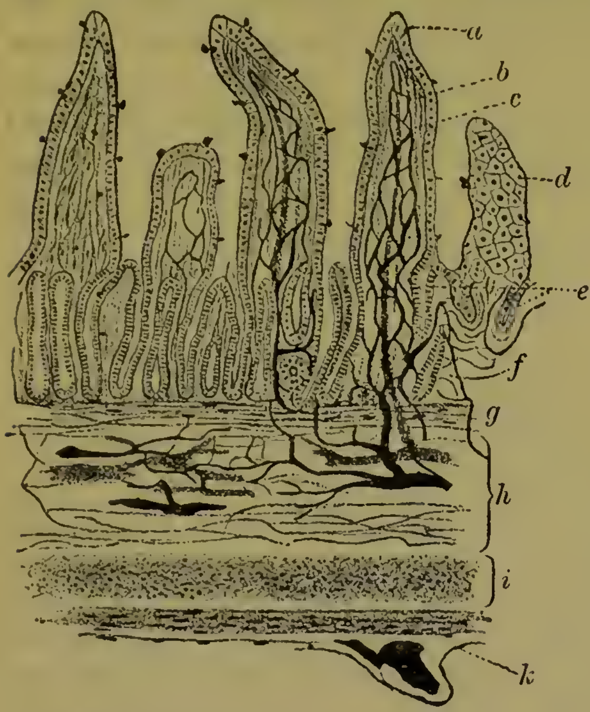


Fig. 89.—Section through the Walls of the Small Intestine:

a, villus with columnar epithelium; *b*, connective tissue forming substance of villus; *c*, blood-vessels; *d*, villus showing ends of the epithelial cells; *e*, Lieberkühnian gland; *f*, the same; *g*, muscularis mucosæ (two layers of muscular film); *h*, lacteals, one running up centre of villus in submucous coat; *i*, internal circular muscular coat; *k*, external muscular coat; serous coat below *k*.

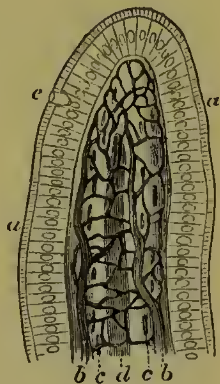


Fig. 90.—Diagrammatic View of the upper part of a *Villus*:

a, *a*, columnar epithelium; *e*, *goblet* cell; *b*, *b*, artery and vein; *c*, nuclei of connective tissue; *d*, commencement of lacteal.

(see p. 44). The human intestine consists of a convoluted tube, which, from a great change in calibre in two different parts, is divided into (1) the small intestine, and (2) the great intestine (figs. 29 and 34). The small intestine is about twenty feet in length, and is divided by anatomists into three portions—the *duodenum*, *jejunum*, and *ileum*, the last

opening into the great intestine. The whole of this tube is connected with the back of the abdominal cavity by a thin web, called the *mesentery*, on which blood-vessels, nerves, and absorptive vessels, the lacteals, ramify before penetrating into and supplying the bowel (see fig. 94, p. 143).

148. MICROSCOPICAL STRUCTURE OF MUCOUS MEMBRANE.—When the small intestine is slit open, it presents a large number of transverse folds, called *valvulæ conniventes* (fig. 91), which are simply doublings of the mucous membrane, so as in little space to increase the surface for absorption. It has also a peculiar velvety appearance, which is due to the fact that it is covered over by innumerable small projections termed *villi* (fig. 89). They are more numerous in the upper than in the lower portions of the bowel. When examined by the microscope, they are found to be prolongations of the mucous membrane, shaped like the finger of a glove, and each is covered by a layer of epithelial cells (fig. 90). Of these there are two kinds : (1) the columnar epithelial cell (fig. 90, *a*, *a*), and (2) a peculiar cell, with an open mouth, called a *goblet* cell (fig. 90, *e*). In the centre we find the commencement of the true absorbent vessel, the *lacteal* (fig. 90, *d*), and surrounding it a network of vessels of very minute size. The villi in the small intestine are to a certain extent comparable to the delicate rootlets of a plant. The latter absorb moisture and soluble nutriment from the soil, while the former are bathed in a nutritious fluid, the chyme, and absorb readily fluids by the blood-vessels, and fatty matters by the

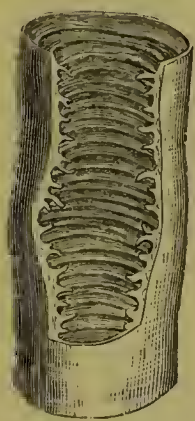


Fig. 91.—Small Intestine distended and hardened by alcohol, and laid open to show the valvulæ conniventes.

lacteals. We find also in the mucous membrane large numbers of minute tubular glands, called *Lieberkühnian glands*, after the anatomist Lieberkühn, who first described them (fig. 89, *e*). In the upper part of the duodenum there are a few racemose glands, like small clusters of grapes, known as *Brunner's glands.*

The great intestine, about five or six feet in length, is so termed because it is so much wider than the smaller one. It is also divided into three parts: the *cæcum*, which is a wide pouch, often of great size in herbivorous animals, and into which the small intestine opens, the entrance being guarded by a valve (fig. 36); the *colon*, which forms the greater part of the large intestine; and the *rectum*, which is situated entirely in the pelvis, and terminates in the anus (see p. 45). The great resembles the small intestine in general respects, but the mucous membrane shows no villi.

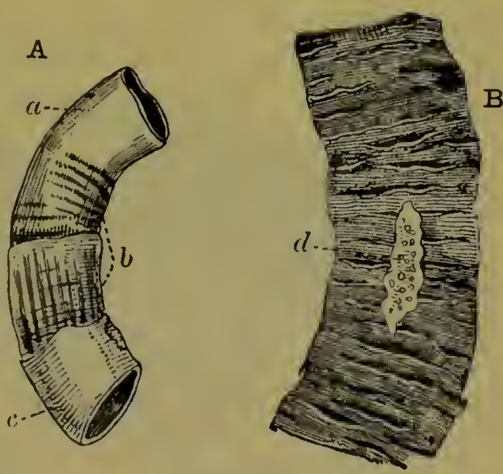


Fig. 92.

A, Coats of Small Intestine, much reduced in size: *a*, mucous; *b*, muscular; *c*, serous. B, Small Intestine, opened to show fold of mucous membrane: *d*, Peyer's patch.

149. Functions of Villi.—The function of the villi is mainly the absorption of fatty matters. (1) The villi exist only in the small intestine where the absorption of fat goes on. (2) They are turgid, enlarged, and opaque during the process of digestion and absorption, and small and shrunken in animals that have been kept fasting for some time before death.

150. Functions of Muscular Coat.—The small intestine has an internal circular and an external longi-

tudinal coat of unstriated muscle, the function of which is to propel the food along the bowel. This is accomplished by alternate contractions and relaxations, and thus a wave-like motion is produced. This motion may be readily seen in the intestines of an animal recently killed, and is termed a *peristaltic action* (fig. 92).

151. Action of Fluids in Small Intestine.—When the food, reduced to a pulpy mass in the stomach, termed *chyme*, passes into the duodenum, it is mixed with three fluids—the bile, the pancreatic juice, and the intestinal juice.

152.—Function of the Bile in Digestion.—The *bile*

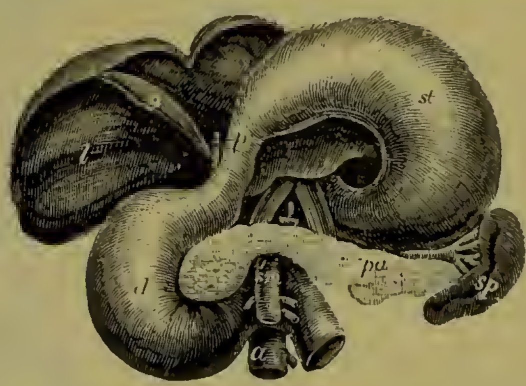


Fig. 93.—The under surface of the Stomach and Liver, which are raised to show the Duodenum and Pancreas:

st, stomach ; *p*, its pyloric end ; *l*, liver ; *g*, gall-bladder ; *d*, duodenum, extending from the pyloric end of the stomach to the front, where the superior mesenteric artery (*sm*) crosses the intestines ; *pa*, pancreas ; *sp*, spleen ; *a*, abdominal aorta.

is an alkaline fluid secreted by the *liver* (the structure of which will be described in connection with the subject of *excretion*, with which it has chiefly to do), and, after having been collected in the gall-bladder (fig. 93, *g*), finds its way into the upper part of the small intestine by a duct, which usually unites with that of the pancreas, *pa*, and opens by a common orifice. As it flows from the liver, the bile is a thin greenish-yellow fluid, sometimes olive-brown ; but when acted on by the gastric juice, it acquires

a distinctly yellow or green hue, hence the appearance of vomited bile. Its main use seems to be (1) to promote the digestion of fatty matters, and it accomplishes this end by a physical action both on the fats and on the intestinal walls, disintegrating the former, and impressing on the latter (by moistening the villi) a peculiar condition which facilitates the absorption of fatty matters. (2) The bile separates nutritious matters from those which are non-nutritious, while it (3) stimulates the muscular movements of the bowels, and (4) arrests putrefaction in the fæces.

153. Chemical Nature of the Bile.—The constituents of the bile are the *bile-salts*, glycocholate and taurocholate of soda; the *bile-pigments*, bilirubin and biliverdin; a mucus-like substance, one of the *nucleo albumins;* and small amounts of cholesterin, soaps, fats, urea, lecithin, and salts—chiefly chloride of sodium and phosphates of iron and calcium. It is neutral, or alkaline, in reaction, and has a specific gravity of about 1030. The amount of solid matter is from 9 to 14 per cent. In human bile, by far the most abundant constituent is glycocholate of soda. The chief difference between the two bile-salts is that taurocholate of soda contains sulphur, while the other does not. Cholesterin, a substance forming the chief constituent of gall-stones, exists only in minute quantities. The fate of the biliary constituents will be considered in treating of the liver.

154. The Pancreatic Juice in Digestion.—The *pancreatic juice* is secreted by a long, narrow, flattened gland called the *pancreas*, or sweetbread, which lies deeply in the cavity of the abdomen, immediately behind the stomach (figs. 37 and 93). It is a lobulated or *racemose* gland, consisting of an immense number of small pouches grouped round the extremities of small ducts. These ducts unite with others, becoming larger and larger, until the great duct of the gland is formed. The secretion is a colourless,

clear, somewhat viscid, and ropy fluid, devoid of any special odour, and exhibiting an alkaline reaction. The functions of the pancreatic juice are (1) to emulsionise the fat of the chyme, and thus promote its absorption. If the duct of the pancreas be tied, and fat be taken as food, a large amount of it will appear in the fæces; and the same result has been seen in the human being in cases of diseased pancreas. The juice appears not only *physically* to emulsionise the fats, but *chemically* to split them up into glycerin and a fatty acid (p. 58). (2) The pancreatic juice also converts any starchy matter, which may have escaped the action of the saliva, into grape-sugar. (3) It acts partially on the albuminous matters, splitting up the peptones into simpler bodies, such as leucin and tyrosin.

155. CHEMICAL NATURE OF THE PANCREATIC JUICE.—An analysis of human pancreatic juice showed it to contain: water, 97·6 per cent.; organic solids, 1·8 per cent.; and inorganic salts, ·6 per cent. From its peculiar action, it has been assumed that four enzymes exist: (1) *trypsin*, an enzyme that decomposes proteids; (2) *amylopsin*, the enzyme acting on starch; (3) *steapsin*, an enzyme having an action specially on fats; and (4) a *milk-curdling* enzyme. These bodies have never been isolated. In addition, the pancreatic fluid always contains some proteid matter, and traces of leucin, tyrosin, xanthin, and soaps. Chloride of sodium is abundant, and there are traces of phosphates and carbonates, both of which cause the alkalinity of the fluid.

156. THE INTESTINAL JUICE IN DIGESTION.—Of the last of the fluids poured into the intestine, the *intestinal juice*, we know little. It is the aggregate secretion of the various glands which occur in the walls of the smaller intestines. It is a colourless, or sometimes yellowish, ropy, viscid fluid, which is invariably alkaline. It seems to unite in itself the leading properties of the pancreatic and gastric

juices—that is to say, it resembles the former in converting starch into sugar, and the latter, in converting albuminous bodies into peptones. The most important action of intestinal juice is that it converts cane-sugar or saccharose and maltose into glucose or grape-sugar, due to an enzyme called *invertin*. Thus all the starch and all cane-sugar is exchanged into glucose before absorption.

157. ACTION OF MINUTE ORGANISMS IN INTESTINAL CANAL.—The contents of the stomach and of the first part of the small intestine are acid, but they gradually become neutral, and then alkaline by admixture with the bile and pancreatic fluid, both of which are feebly alkaline. Such a medium is one in which numerous minute organisms of the nature of the lowest class of fungi, known as *bacteria*, live and grow, and accordingly we find these lowly organisms present in enormous numbers in the bowel. There can be no doubt these set up chemical actions independently of the enzymes we have considered. Thus they set up the lactic acid change, by which the sugar in milk is changed into lactic acid; this lactic acid they further decompose into butyric acid, carbonic acid, and hydrogen; cellulose, found in the cells of vegetable matter, they convert into marsh gas and carbonic acid, the two chief gases found in the intestine. The bacteria also act on fats, liberating fatty acids, and causing the matter in the lower part of the intestine to become acid. Lastly, they act on proteids, giving rise to substances known as indol, skatol, and phenol, which give the bad odour to the fæces.

158. CHANGES IN THE GREAT INTESTINE.—The line of demarcation between the small and large intestine is very obvious, and by the peculiar arrangement of the *ileo-cæcal valve*, which guards the entrance of the small into the great intestine, matters are allowed to pass forward with facility, while regurgitation is impossible (see fig. 36, p. 45). Structurally, the great intestine has no villi, and is

more capacious, though much shorter, than the small intestine. Its contents differ very materially from those which are found in the small intestine, and constitute the *fæces*. They are more solid and homogeneous, and are often moulded into a definite shape. The only essential change which the matters in the great intestine undergo in this part of their course is, that they increase as they pass onward in solidity, in consequence of the absorption of fluid from them by the vessels of the mucous membrane. They are propelled onwards into the rectum by the peristaltic action which has been already described, and are at last expelled by a partly voluntary and partly reflex effort.

The fæces consist chiefly of undigested materials (such as vegetable cellular tissue, fragments of tendon, skin, and disintegrated muscular fibre), but also of material derived from the mucous membrane of the great intestine. It is in the great intestine the chyme first acquires a fæcal odour, said to be due chiefly to the decomposition of albuminous matters, which increases in intensity as the material passes along the bowel.

The colour of the fæces varies with the food. With a mixed diet, they are of yellowish-brown tint; on a flesh diet, much darker; and on a milk diet, yellow. Their reaction is usually alkaline. About four and a half ounces in ordinary circumstances are voided daily.

Questions.

147. Describe shortly the anatomical parts of the small intestine. What is the mesentery?

148. Describe the structure of a villus.

150. How are matters propelled along the bowels?

152, 153. What are the chief matters in bile?

154. What is the structure of the pancreas? Where do the bile and pancreatic fluid enter the bowel? What is the action of pancreatic juice on food stuffs?

158. How does the great differ from the small intestine? What matters are voided as fæces?

CHAPTER IV.

ABSORPTION OF NUTRITIOUS MATTER.

159. General.—As the chyme is propelled along the alimentary canal, the watery portion, holding various substances in solution, is absorbed by the *blood-vessels*, while the fatty matter is taken up by the *lacteals*. It is believed that absorption, so far as the blood-vessels are concerned, is partly a physical process dependent on osmotic action, and partly a vital process due to the selective action of the living epithelial cells clothing the surface of the mucous membrane. The absorption of fatty matter depends on the activity of the epithelial cells covering the villi. The whole of the nutritive material thus separates itself into two parts: one which passes directly into the blood, and the other which enters

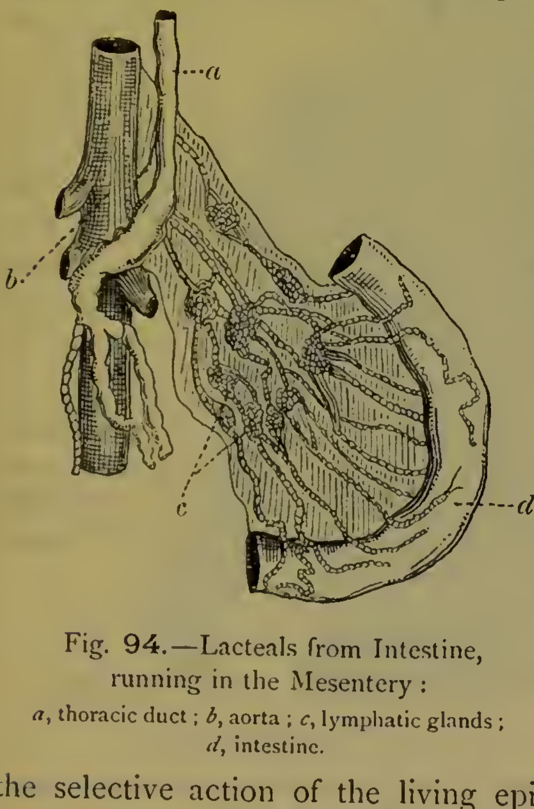


Fig. 94.—Lacteals from Intestine, running in the Mesentery:
a, thoracic duct; *b*, aorta; *c*, lymphatic glands; *d*, intestine.

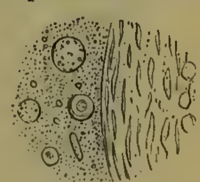


Fig. 95.
Drop of Chyle:
On the left, corpuscles lying amongst molecular matter; on the right, corpuscles altered by the addition of acetic acid.

the lacteals, and in these becomes a milky fluid called the *chyle*. It is important to remember that all the blood circulating in the digestive organs, and taking up soluble nutritive matters, must pass through the liver before

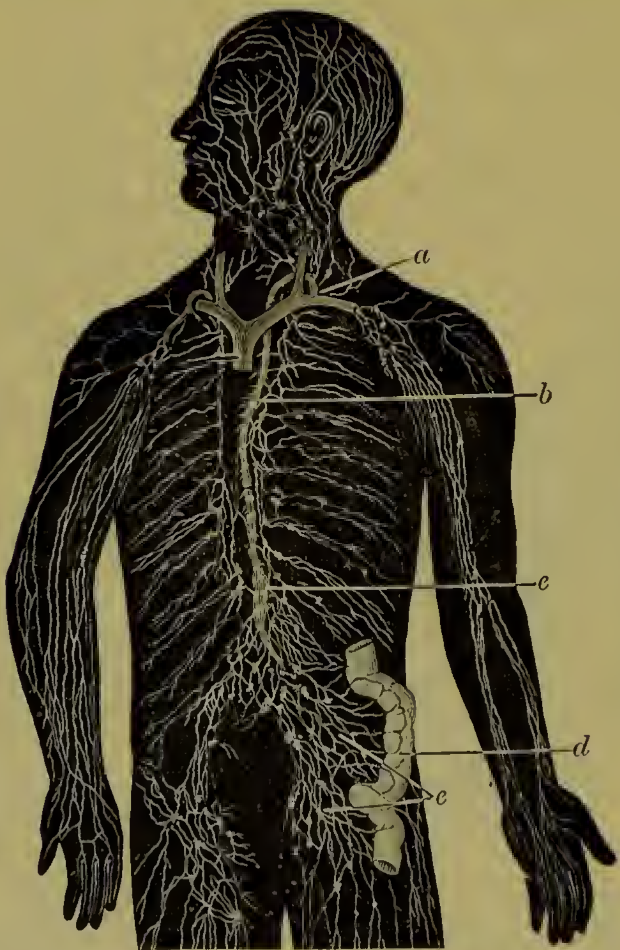


Fig. 96.—The Absorbent System of Man :
a, junction of thoracic duct with left subclavian vein ; *b*, thoracic duct ; *c*, receptaculum chyli ; *d*, portion of intestine ; *e*, lacteals.

entering the general circulation, and from it the cells of the liver select and elaborate their secretion. But the chyle passes into the blood indirectly. It is first conveyed to numerous glands in the neighbourhood of the intestines,

called *mesenteric glands* (see SANGUIFICATION) (fig. 98). Before entering these glands it is a milky fluid, essentially molecular; but after it has passed through the glands it is found to contain small granular cells, similar to colourless blood-cells, termed *chyle-corpuscles*, along with much molecular matter, known as the *molecular basis of the chyle* (fig. 95). Before passing through the glands, the chyle does not coagulate on heating, but after doing so it coagulates readily. The lacteal vessels proceeding from these glands unite with corresponding sets of vessels from the lower limbs, called *lymphatics*, in a wide cavity opposite the last dorsal vertebra, the *receptaculum chyli* (see fig. 96). From this cavity a duct, the *thoracic duct*, ascends through the thorax, receives branches from the left arm and left side of the head, and unites with the venous system at the root of the neck on the left side, the point of junction being where the left internal jugular vein unites with the great vein of the left arm, the left subclavian. The lymphatics of the rest of the body unite to form the right lymphatic duct, which joins the venous system at a corresponding point on the opposite side of the root of the neck. The whole of the chyle, therefore, passes into the blood at the root of the neck.

QUESTION.

159. What is the distinction between chyme and chyle? Where is chyle found? Where does chyle enter the blood? Trace the course of the thoracic duct.

CHAPTER V.

SANGUIFICATION.

160. GENERAL.—By this term we mean the making of blood. In the lowest animals, such as in the amœba, we find no circulating nutritious fluid. When we ascend

higher in the scale, we find a colourless fluid containing molecules made to move in certain definite directions by the action of cilia in the general cavity of the body, as in a sea-anemone. Still higher we meet with a colourless fluid circulating in vessels, frequently communicating with the body-cavity, and propelled by a special contractile organ, as in the sea-urchin or ascidian; and at last we meet with a coloured fluid, circulating in vessels separate from the body-cavity, and having a propelling organ, or heart, of more or less complex structure, as in all the vertebrata.

Fig. 97.—General View of the Anatomy of a Lymphatic Gland: The arrows indicate the direction of flow of lymph. *a*, body of gland; *b*, lymphatic entering gland.

161. Sources of the Blood.—The blood, in the higher animals and in man, is derived from five sources: (1) from materials, mostly of the nature of *fats*, absorbed by the lacteals in the primary digestion of the food in the alimentary canal (*chyle*); (2) from soluble matters, such as *water*, soluble *mineral* matters, *sugar*, and *proteids* derived from peptones absorbed by the blood-vessels, and first of all sent through the liver; (3) from cells formed in certain glands called *blood-glands*, found in various parts of the body; (4) from materials re-introduced into the blood from the tissues—products of the decomposition and solution of portions of these tissues consequent on their vital activity (*lymph*); and (5) from a small amount of matter which may be absorbed by the *skin*.

162. The Blood-glands.—The so-called blood-glands are—the *spleen*, a large organ found almost in juxta-

position with the left end of the stomach; the *suprarenal capsules*, two organs found in the lumbar region, one on the top of each kidney; the *thymus*, a gland found in the thorax, immediately behind the breast-bone, of larger size before birth and during the earlier years of life than during adult life; the *thyroid*, a gland existing in front of the box of the larynx; the *glands of Peyer*, in the mucous membrane of the small intestine; and lastly, the *lymphatic glands*, which we find in many parts of the body, such as in the

Fig. 98.—Section of a Lymphatic Gland:

a, strong fibrous capsule sending partitions into the gland; *b*, partitions between the follicles or pouches of the *cortical* or outer portion; *c*, partitions of the *medullary* or central portion; *d*, *e*, masses of retiform tissue filled with white cells in the pouches of the gland; *f*, lymph-vessels which bring lymph *to* the gland, passing into its centre; *g*, confluence of those leading to the efferent vessel, *h*, which carries the lymph away *from* the gland.

groin, the armpit, and the neck. The structure of a lymphatic gland will be understood from the description of fig. 98. All of these glands agree in certain points of their anatomy: they have no ducts to carry off the secretion, except we regard as such the numerous lymphatics by which they are supplied; they consist of shut sacs, containing (except the thyroid and suprarenal capsules) a tissue called *adenoid* or *retiform* tissue, in the meshes of the network of which there are white blood-corpuscles;

and finally, they are richly supplied with blood-vessels, lymphatics, and nerves.

163. NATURE OF LYMPH.—The various tissues of the body are nourished by blood brought into close proximity to them by minute vessels termed *capillaries.* While the blood is passing through the capillaries, part of it transudes through their walls to nourish the tissues, or, possibly, it is secreted by living cells in the capillaries and tissues. A portion of this fluid or *plasma* is taken up by the tissues, and the other portion is left behind, constituting the fluid found in almost every tissue, to which it owes its softness and moistness. The tissues perform certain functions, and in doing so undergo disintegration, the materials resulting from which pass into a fluid condition. This fluid matter resulting from the disintegration of the tissues, together with the excess of nutritious fluid which has transuded from the vessels, is called *lymph*, and is taken up by the commencements of a number of minute vessels termed *lymphatics.* The lymphatics carry the lymph to glands distributed here and there throughout the body, called *lymphatic* glands, where it is acted upon in such a manner as to fit it for being carried back again into the blood. Thus the lymph results partly from matters produced by the tear and wear of the tissues, but these waste-products the bodily economy, like a manufactory, uses up as far as possible. The kernels or swellings in the armpit during a whitlow, or after poisoning, are swollen lymphatic glands. The lymphatic glands of the mesentery, or web connecting the bowel with the body, elaborate chyle, not lymph, and are termed *mesenteric* glands. In the lymphatic glands, also, the lymph is brought into close relation with the blood, and interchanges between these fluids probably take place.

164. BLOOD, CHYLE, AND LYMPH CONTRASTED.—Blood and chyle have already been described. Lymph is a slightly yellowish or pale fluid, having a specific gravity of about 1018. It contains numerous corpuscles—*lymph-corpuscles*—which are of the same nature as the colourless cells in the blood. Lymph is distinguished from chyle by having in it almost none of the fine molecular matter present in chyle. We may compare the

composition of one hundred parts of each of the three fluids in man, thus :

	Lymph.	Chyle.	Blood-plasma.
Water	95·0	90·5	90·2
Solids	5·0	9·5	9·7
Fibrin	0·1	0·1	0·4
Albumin	4·1	7·0	7·8
Fat	trace.	1·0	trace.
Extractives	0·3	1·4	0·56
Salts	0·5		0·85

From this table we learn (1) that chyle and lymph, especially the latter, contain less proteid matter than blood ; (2) that fibrin is in greatest abundance in blood ; and (3) that fat is in greatest abundance in chyle. The three fluids, however, when we exclude the corpuscles, bear a striking resemblance.

165. STRUCTURE OF THE SPLEEN.—This is the largest and most important of the blood-glands. It is of an oblong flattened form (fig. 93), soft, of very brittle consistence, highly vascular, of a dark bluish-red colour, and situated near the cardiac or left end of the stomach. On cutting into it, a section shows the presence of fibrous bands, termed *trabeculæ*, united at numerous points with one another, and running in all directions. The *parenchyma*, or proper substance of the spleen, occupies the interspaces of the above-described areolar framework, and is a soft pulpy mass of a reddish-brown colour, consisting of coloured and colourless blood-corpuscles and protoplasmic matter. The venous blood of the spleen is carried away by the splenic vein, which contributes to form the great portal venous system carrying blood to the liver ; while arterial blood is supplied by the splenic artery. The branches of the latter subdivide and ramify like the branches of a tree (fig. 99), with the *Malpighian* or *splenic corpuscles* attached to them like fruit (*c*, *c*, *c*). These corpuscles, originally discovered by Malpighi, appear in sections as whitish spherical bodies filled with granular matter and many nucleated cells. They are in reality elongated or somewhat egg-shaped masses of retiform tissue surrounding or attached to the wall of a blood-vessel. The *spleen-pulp* contains cells

of various kinds in retiform tissue (fig. 100). Many theories have been advanced as to the functions of the spleen; but the one most generally adopted is, that it has to do (1) with the formation of the colourless corpuscles of the blood; and

Fig. 99.
Portion of Splenic Artery, *a*, *b*, *b*, having Malpighian bodies attached, *c*, *c*, *c*.

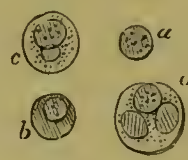


Fig. 100.
Cells from the Spleen Pulp:
a, similar to a colourless corpuscle of blood; *b*, nucleated cell; *c*, bi-nucleated cell; *d*, cell containing three cells in interior.

(2) with the destruction of effete or worn-out red corpuscles. Occasionally, in spleen pulp, we meet with large cells similar to *d* (fig. 100), inclosing two or three cells similar to blood-corpuscles. It is to be noted that the spleen has been successfully removed from animals without any marked disturbance of the system. In these circumstances some of the other blood-glands probably did its work.

166. The other Blood-glands.—Our knowledge of the functions of the other organs classed as blood-glands is still uncertain. The *lymphatic glands*, found in many localities, such as the groin and armpit; the *thymus*, a gland in the thorax, behind the sternum, reaching its greatest size in very early life, and gradually wasting towards adolescence; the *glands of Peyer*, in the intestinal mucous membrane; and the *red marrow of bone* have all to do with the production of blood-corpuscles. The red marrow of bone, in particular, is the birthplace of red corpuscles. In these organs we find adenoid (retiform) tissue, but this tissue exists in other parts of the body. It exists beneath the mucous membranes, and here and there it forms knots or masses, as in the *tonsils*, and in the *solitary glands of Peyer*. In the meshes of this tissue we

always find numerous white blood-corpuscles, which are probably developed here. Many of these white corpuscles, called *leucocytes*, or *wandering cells* (because they wander about in the tissues by their amœboid movements), are believed to guard the body against the attacks of its invisible foes, *bacteria*, *bacilli*, and other organisms that are injurious to the body, when they obtain entrance into the tissues. The white cells destroy these micro-organisms by eating them up (*phagocytosis*), and thus a war is carried on between the white cells and these minute parasites, which are mostly of the nature of fungi.

The other so-called blood-glands have functions obscurely concerned in removing from the blood various waste-products. These waste-products are probably decomposed into simpler substances, and are then eliminated by the true organs of excretion. Thus the *suprarenal bodies* decompose effete pigment, and the *thyroid body* destroys the constituent of mucus called mucin. In all likelihood, however, these organs have other functions yet unknown. The *pineal gland* is an abortive ancestral eye, and the *pituitary body* is a very much altered gland, partly of nervous, partly of mucous origin.

Questions.

161. From what sources is the blood continually replenished?
162. Enumerate the blood-glands.
163. What is lymph? Compare it with chyle and blood.
165. Describe the structure of the spleen. What functions have been attributed to the spleen?
166. What functions may be performed by leucocytes?

CHAPTER VI.

THE LIVER.

167. General Description.—This organ is the largest and heaviest gland in the body, weighing, on an average, 65 ounces avoirdupois. It is situated on the right side, beneath the lower ribs (fig. 29). It consists of five lobes, of a dark reddish colour, and these lobes are divided into

lobules. The lobules are bound together by areolar tissue, and the structure of all is alike. The liver is supplied with the blood from which it elaborates its secretions by the portal vein (fig. 72), a vessel which collects all the blood circulating in the stomach, spleen, and intestines. The portal vein divides and subdivides in the liver, till it forms a plexus of minute vessels between and in the lobules, from which originate the radicles of the hepatic vein (fig. 72), a vessel which carries the blood from the liver to the *inferior vena cava.* The connective tissue of the liver, and its vessels and nerves, are supplied by a special artery, the hepatic artery (fig. 75, *n*). The proper secreting structure of the liver consists of numerous compressed cells, about the $\frac{1}{1000}$th of an inch in diameter, called *hepatic cells* (fig. 101, *b*). These cells secrete materials from the blood, which they elaborate into bile. This secretion passes into minute ducts, the bile-*ducts*, which originate in minute spaces, *a*, between the cells, *b*. These ducts convey the bile out of the liver; and after it has become inspissated and mixed with mucus, from small mucous glands in the larger ducts, and from the gall-bladder (fig. 37, *b*), it is poured into the duodenum.

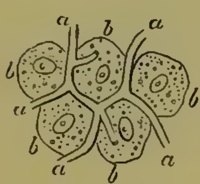


Fig. 101.
Hepatic cells, *b*; with the bile-ducts, *a*, originating amongst them, *b*.

168. Circulation in the Liver.—When we examine a thin section of the liver, we see irregularly polygonal areas more or less sharply differentiated by connective tissue. These are the *lobules* of the liver, and they consist of hepatic cells and blood-vessels. Usually slightly oval, or in transverse section polygonal, the length of a lobule is $\frac{1}{12}$th inch, and its breadth $\frac{1}{25}$th inch. Around the circumference of each lobule lie the ramifications of the portal vein, called the *interlobular* veins. Capillaries pass from these into the lobule, and they unite to form a central vein (fig. 102).

Fig. 102.

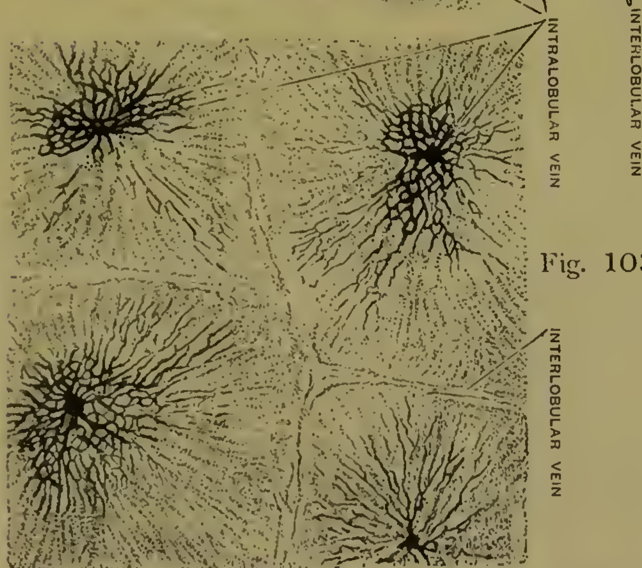


Fig. 103.

Fig. 102.—Section of Rabbit's Liver near the surface. Injected from the Portal Vein.

Observe three lobules. The injection has filled the branches of the portal vein, called interlobular veins, and in the lobule to the left it has entered the lobule and passed on to the central vein (intralobular vein).

Fig. 103.—Section of Cat's Liver near the surface. Injected from the Vena Cava.

Observe four lobules. The injection has filled the central vein and the capillaries leading into it, but it has not entered the portal capillaries, or interlobular veins.

These capillaries form networks with the vessels in adjoining lobules. The spaces in the capillary network are occupied by hepatic cells, and these are arranged in a radial manner round the vessel in the centre of the lobule. This central vessel is termed the *intralobular* vein (fig. 103). The intralobular veins are the beginnings of the hepatic veins. Each intralobular vein opens into a *sublobular* vein, which runs on one side of the lobule, and by the junction of the sublobular veins the hepatic veins are formed. The branches of the *hepatic artery* run along with those of the portal vein, and terminate in the interlobular tissue, where the branches of the portal vein and of the hepatic veins and the bile-ducts wind round them in a spiral manner. The small veins originating from the plexus formed by the hepatic artery open into interlobular veins of the portal system. The hepatic artery also supplies a network of fine capillaries found in the capsule of the liver. The course of the blood-vessels is therefore as follows: The portal vein enters the fissure of the liver, divides again and again into finer and finer branches which run between the lobules (*interlobular veins*). From these, small capillaries enter the lobules and terminate in the central veins (*intralobular veins*). Several of such veins form a sublobular vein, and these form the hepatic vein. The capillaries of the hepatic artery terminate outside the lobules.

Unlike what we find in other glands, very few hepatic cells bound the lumen of the gland, not more than two being related to a single lumen or bile-capillary, and the structure is complicated by the arrangement that bile-capillaries do not lie on one but on several sides of a hepatic cell. These form a meshwork in which the hepatic cells are situated. The bile-capillaries, or beginnings of the hepatic ducts, are passages among the hepatic cells. Sometimes they are termed *intralobular bile-passages*. At

the margins of the lobules they pass into the interlobular bile-ducts, which have a distinct wall, composed of a structureless basement membrane and of flat epithelial cells. By the union of interlobular ducts the larger bile-ducts are formed; these have a cubical or columnar epithelium.

169. FUNCTIONS OF THE LIVER.—The more obvious function of this organ is the secretion of bile, and for many years this was supposed to be its sole function. Research, however, has shown that the liver is the seat of very active changes which are hidden from the eye, and it has also been ascertained that these changes are as necessary for the well-being of the body as is the secretion of bile. The liver is not to be regarded, therefore, as a gland having only to do with the secretion of one of the digestive fluids; indeed, as has been shown, the bile plays only a subsidiary part in the digestive process. It is important to note that the liver receives a large amount of blood by the portal vein, and that this blood is rich in materials absorbed by the capillaries of the stomach, intestines, and spleen. The blood of the portal vein, therefore, during absorption following the digestion of food, is not like ordinary venous blood. Thus all matters absorbed from the alimentary canal in the first instance pass to the liver. From this blood the hepatic cells select certain materials, proteids, fats, and carbo-hydrates (in the form of glucose), and submit these to various processes, with the result of forming other substances, some of which are thrown out in the bile, while others are retained in the body for further use.

170. The liver, from this point of view, has to do with the following processes: (1) the formation of *bile;* (2) the formation in some circumstances of *fatty matter* stored up for a time in the hepatic cells; (3) the formation from glucose chiefly of a carbo-hydrate, a kind of animal starch, called *glycogen;* and (4) the formation of *urea* from various

substances originally derived from proteids, traceable back either to the proteids of the food or the proteids of the tissues, or to both. During embryonic life the liver is also the seat of the formation of blood-corpuscles. This function is not carried on during adult life, but it is not improbable that even then in the liver there may be the destruction of effete or worn-out red blood-corpuscles, and undoubtedly the liver is the seat of the decomposition of a part of the worn-out hæmoglobin of the red blood-corpuscles. We shall very shortly discuss each of these functions.

(*a*) *The Formation of Bile.*—This has been already described. We would only add that bile may be regarded as one of the waste-products arising from the changes happening in the liver. This waste-fluid—the bile—is still, however, put to subsidiary uses in the processes of digestion and absorption.

(*b*) *The Formation of Fat.*—Little globules of fatty matter are often found in the hepatic cells. These globules may sometimes so overload the cell as to hide the nucleus, and then we have a fatty liver. During starvation this fat may be used up.

(*c*) *The Formation of Glycogen.*—This undoubtedly is one of the most important functions of the liver, and it is part of a general process for the using up of carbo-hydrates, known as *glycogenesis.* The glucose brought to the liver from the intestinal canal is changed by the hepatic cells into *glycogen*, a substance in many ways like ordinary starch. Glycogen differs, however, in giving a reddish-brown colour with iodine instead of the well-known blue colour given when a solution of iodine is brought into contact with starch paste or with a solution of starch. As glycogen may be formed in the liver even when no carbo-hydrates are taken in the food, it must be formed from the proteid matter existing in the hepatic cells. The glycogen may remain stored up in the hepatic cells for a

considerable time. When an animal dies, the glycogen thus stored is quickly changed into sugar, so if we make an infusion of dead liver with hot water, we readily obtain a solution of sugar, and not of glycogen. During life, and probably in the intervals when digestion and absorption of carbo-hydrate is not going on, the glycogen leaves the hepatic cells and is carried by the blood-stream all through the body. It thus reaches the muscles in particular, and there it is changed back again into sugar, and is then used up for the nutrition of the muscular tissue. Some suppose that the change of glycogen into sugar occurs before the glycogen leaves the liver. In this way the muscles receive an ample supply of carbo-hydrate, and it is from this that most of the energy of the muscle is derived.

(*d*) *The Formation of Urea.*—We have seen that the proteid matter is first changed into peptone by the gastric juice, or into bodies somewhat similar by the pancreatic juice. These peptones are converted into serum-albumin at the moment of absorption, and in this way, say after a diet rich in meat, the liver cells receive a large supply of proteid matter. Some of this may pass through the liver unchanged, and be carried to the muscles and other tissues for their nourishment. A portion, however, appears to be decomposed by the hepatic cells, with the formation of *urea*, which passes into the blood, and is there thrown out by the kidneys into the urine. Thus a diet rich in proteids—in other words, a flesh diet—always causes an increase in the urea eliminated, whereas a diet poor in proteids, as with most vegetable foods, causes a diminution in the amount of urea. It is not to be supposed, however, that one of the functions of the liver is to form urea when we take an excess of proteid in the food. It is more likely that the other portion of the proteid, the part left after the urea has been removed, is of great nutritional importance, and, as it now contains no nitrogen (all the nitrogen

having gone off in the urea), it may be changed into fat or glycogen. There is also evidence to show that urea may be formed from leucin and tyrosin formed by pancreatic digestion. These crystalline bodies are absorbed from the bowel and carried to the liver, there to be submitted to further chemical changes leading to the formation of urea. Lastly, the liver may form urea, or other nitrogenous bodies, such as uric acid, from nitrogenous bodies that have come from the waste of muscular tissue.

(*e*) *Destruction of Waste Hæmoglobin.*—As already mentioned, worn-out red corpuscles are destroyed in the spleen. One of the substances thus set free is the pigment *hæmoglobin*, which is carried to the liver, there further decomposed, and the refuse thrown into the bile, appearing in this fluid as the *bile-pigments*—namely, *bilirubin* and *biliverdin*. Some of the pigmentary products thus formed are carried to the kidneys, and are there eliminated as the pigment of the urine, *urobilin*, &c., and others may be deposited in the tissues.

171. Fate of the Bile Constituents.—The bile passes, as has been described, into the duodenum, and there it has an influence both on digestion and on absorption. It is not all voided in the fæces, but a portion is absorbed and returns to the liver. The bile-salts, glycocholate and taurocholate of soda, exist in the fæces only to a small extent, and as much as seven-eighths of the total amount are absorbed and sent back to the liver. It is likely that in the intestine they are decomposed into taurin, glycocin, and cholalic acid. Small amounts of these appear in the fæces; the remainder return to the liver. Their ultimate destination is not well known, but it has been stated that the glycocin is changed into urea and the taurin into a body called taurocarbamic acid, both of which are then eliminated by the kidneys. The bile-pigment becomes *stercobilin*, the pigment of the fæces. Finally the cholesterin and mucus pass off in the fæces.

QUESTIONS.

167, 168. Describe the minute structure of a lobule of the liver.

168. From what sources does the liver receive blood? How does its structure differ from that of an ordinary secreting gland?

170. Enumerate the functions of the liver. (*c*) How does glycogen differ from common starch? (*d*) In what ways may urea be formed? (*e*) What is the origin of the bile-pigments?

171. What becomes of the chief constituents of the bile?

CHAPTER VII.

THE RESPIRATORY SYSTEM.

172. GENERAL STATEMENT.—The organs and process of respiration now claim our attention. We have already stated that the blood of the arteries differs in colour from that of the veins, the former being of a bright scarlet tint, while the latter is purplish in colour. The *arterial* represents pure, and the *venous* impure blood; the change from the former to the latter having taken place in the *capillaries*, which form the bond of union between the termination of an artery and the beginning of a vein (fig. 77). The chemical differences between arterial and venous blood are slight, except in relation to the gases held in solution in these fluids. The two kinds

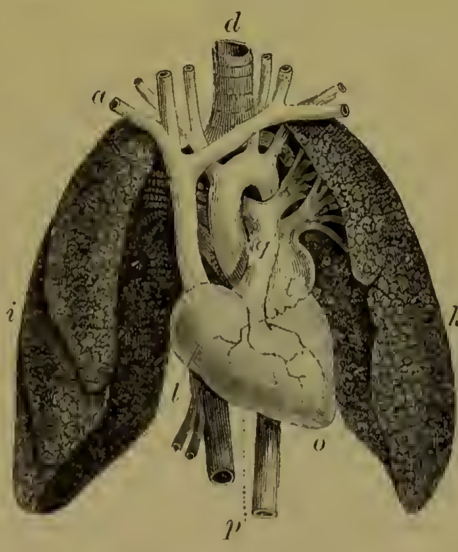


Fig. 104.

The Lungs and Heart (viewed in front): *a*, aorta; *d*, windpipe; *i*, *k*, lungs; *l*, *l'*, right and left auricles of heart; *p*, right ventricle; *o*, apex of left ventricle; *q*, pulmonary artery.

of blood differ widely in this respect, there being a smaller quantity of oxygen, and a greater quantity of carbonic acid, in venous than in arterial blood.

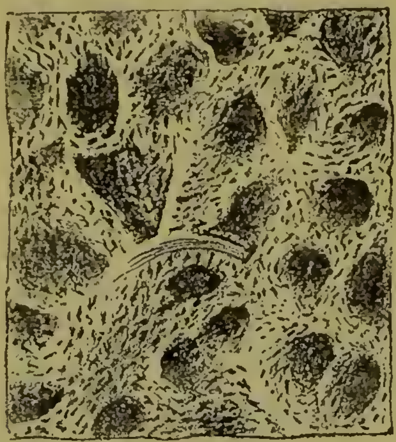


Fig. 105.—Blood-capillaries of Lung injected.

173. The organs by which the impure and dark venous blood is converted into pure, bright scarlet, arterial blood, are the *lungs*, and the agent by which this change is effected is the oxygen of the air we breathe. In their simplest form, as they occur in certain reptiles, the lungs are air-sacs, existing as two elastic membranous bags, having small honeycomb-like depressions known as 'air-cells' on their inner surface, communicating with the external air by a tube known as the windpipe or *trachea*, which opens through the larynx or organ of voice into the throat. These bags are lined by a delicate, thin, and moist mucous membrane, in which is imbedded a network of capillaries, through which all the blood is driven by the heart (figs. 105 and 106). The moist partition between the blood in this network and the air in the interior of the lungs is so thin as to allow an interchange between the gases of the blood and the gases of the air—that is to say, oxygen passes from the air in the air-cells into the blood, while carbonic acid gas passes outwards from the blood into the air in the air-cells. This is a phenomenon dependent largely on the laws of diffusion and admixture of gases through animal membranes, but the living cells lining the air-cells take part in the process.

Fig. 106.—Network of Capillaries of Lung.

The air of expiration, as it passes over the moist air-passages, becomes laden with aqueous vapour.

174. CONDITIONS OF RESPIRATION.—In the higher animals and in man, these essential parts are much complicated and modified in a variety of ways. The anatomical details (figs. 29, 38, and 104) may be considered under the following heads: *Firstly*, the lungs afford an immense extent of mucous membrane, covered by vascular network, through which, as in the simpler form, the blood flows in innumerable minute streamlets (fig. 105), only separated by a thin membrane from the atmospheric air that has been inhaled; *secondly*, there is such an arrangement of the circulating system, that fresh blood is perpetually driven from the right side of the heart through the lungs onwards to the left side of the heart; and *thirdly*, there are arrangements for the frequent and regular change of the air contained in the lungs.

175. SPECIAL ANATOMY OF THE ORGANS.—We shall first consider the lungs and the passages leading to them. The back of the mouth, or pharynx, is connected with the outer air in two ways—namely, by the nasal passages and nostrils, and by the mouth (figs. 31 and 38). Through either of these channels the air may pass to and from the lungs, but the nostrils are, properly speaking, the entrances to the respiratory system. Behind the root of the tongue, we find a chink or aperture, the *glottis*, bounded laterally by two folds of membrane called the *vocal cords*, which may be more or less widely separated from each other (see VOICE). This aperture is guarded by a leaf-like lid, the *epiglottis*, which can be closed when expedient, so as to prevent the entrances of particles of food, drink, &c. (fig. 31). The glottis opens downwards, into a box-like chamber called the *larynx* (which is the organ of voice); and leading downwards from the larynx runs the *trachea*, or windpipe, a tube kept permanently open for the passage of air, by

cartilaginous rings that surround the anterior two-thirds of it. These are united, and the back of the tube is formed, by a fibrous membrane or muscle. The windpipe, which is easily felt by the hand, and lies just below the projecting part of the larynx, popularly known as 'Adam's apple,' is about four and a half inches in length, and about three-fourths of an inch wide. Passing into the cavity of the chest, it divides into two branches, which are termed the right and left *bronchi* (fig. 104). Each bronchus enters the lung of its own side, and divides into a great number

Fig. 107.
Air-tube ending in Air-vesicles :
a, pleura.

Fig. 108.
Scheme of Air-vesicles :
a, blood-vessels ; *b*, air.

of smaller tubes, called the *bronchial tubes*, which again go on subdividing (fig. 38). These finest tubes end in elongated dilatations, the *infundibula*, from the walls of which bulge out the air-cells, averaging $\frac{1}{40}$th of an inch in diameter (figs. 107 and 108). If we can conceive a bunch of grapes with its stem and all its minute branches, and the grapes attached to the ends of these, to be hollow, we get a good idea of the mode in which the lung is constructed, except that it does not represent all the

sacculation or partitioning of the terminal 'cells.' It is in consequence of the air included in these 'cells' that the lungs have a soft spongy feeling, and crackle when compressed between the fingers. Each lung is invested by its own investing serous membrane, termed the *pleura*, which serves the double purpose of facilitating the movements necessary in the act of respiration, and in suspending each lung in its proper position (fig. 107, *a*).

176. General Description of Process.—The *blood* is being perpetually changed, and driven in a constant current through the lungs by the action of the heart, the venous or impure blood being collected in the right ventricle, and thence conveyed by the pulmonary artery into the lungs. In these, again, it gives off carbonic acid and aqueous vapour, and absorbs oxygen (as already described); after these changes, it is collected, and returned to the left auricle by four vessels called the pulmonary veins (fig. 73).

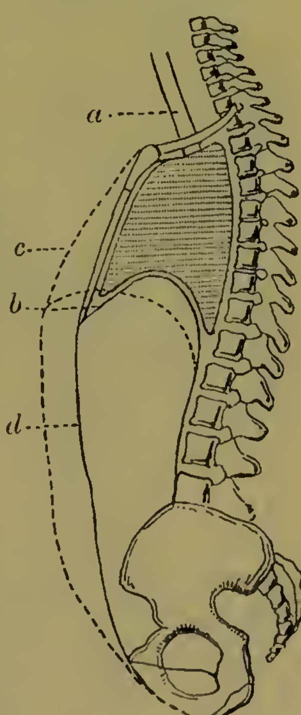


Fig. 109.—Diagram showing Changes of Chest in Respiration : *a*, windpipe; *b*, diaphragm; *c*, inspiration; *d*, expiration.

The mode in which the *air* is renewed in the lungs next requires notice. This is effected by the respiratory movements, which consist in alternate acts of *inspiration* and *expiration*, with an intervening *pause* before the process is renewed. An adult man in a sitting position performs the respiratory act from thirteen to fifteen times in the minute, but much more rapidly if taking exercise. At each inspiration, about 30 cubic inches of air are inspired, and at each expiration

nearly the same volume is exhaled, allowance being made for temperature, which in the exhaled air may equal that of the blood. From 300 to 400 cubic feet of air thus pass in and out of the lungs of a man at rest in the course of twenty-four hours, and these are charged with carbonic acid, and deprived of oxygen to the extent of nearly 5 per cent.; or, to put it in another form, about 18 cubic feet of the one gas are taken in, and of the other gas are given off. The quantity of carbon thus excreted in the form of carbonic acid gas is nearly represented by eight ounces of pure charcoal. The amount of watery vapour separated by the lungs daily varies from six to twenty ounces, according to the diet, exercise, temperature, humidity of the air, &c.

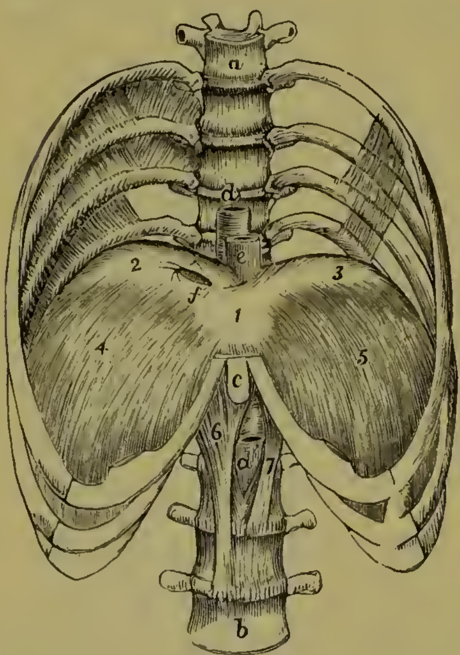


Fig. 110.—The lower part of the Thorax, opened to show the upper side of the Diaphragm from before:

a, sixth dorsal vertebra; *b*, fourth lumbar vertebra; *c*, ensiform cartilage; *d*, *d'*, aorta; *e*, œsophagus; *f*, opening for inferior vena cava. 1, 2, 3, trefoil tendon; 4, 5, central portions of diaphragm; 6, right, and 7, left crus of diaphragm.

177. Mechanism of Respiration.—The chest (or thorax, as it is termed by anatomists, fig. 12) is so constructed as to be capable of enlargement in height (vertically), in depth (or from the front backwards), and in width (or from side to side). Its height is increased mainly by the descent of the diaphragm (figs. 109 and 110), and to a certain extent by the elevation of the ribs, and the widening of the intercostal spaces; while its depth and width are increased by the elevation of the ribs which

carry forward and elevate the breast-bone (or sternum), especially at its lower end, and which are slightly rotated on an imaginary axis, joining their extremities, whereby their central portion is raised, and to a small extent carried away from the mesial plane of the chest. It is only in forced or deep inspiration that all these means of enlarging the chest are called into play. An ordinary inspiration is attended in men with very slight elevation of the ribs (about one-twentieth of an inch), while in adult women the elevation is greater, especially in the upper ribs; the cause of this difference in the sexes probably lying in the narrower waist of the female requiring a compensation in the upper part of the chest. In early life, and when women are untrammelled by conventional garments, there appears to be no difference. There are three varieties of ordinary respiration, namely: (1) *abdominal*, or that chiefly effected by the diaphragm, and seen in the motion of the walls of the belly; (2) *costo-inferior*, or that in which the seven lower ribs are observed to act; and (3) *costo-superior*, or that effected in a considerable degree by the upper ribs. The first variety occurs in infants up to the end of the third year, and in males generally; the second, in boys after the age of three, and in men; and the third, in adult females (fig. 109).

178. NUMBER OF RESPIRATORY MOVEMENTS, &c.—Every complete act of respiration is divisible into four parts—namely (1) Inspiration; (2) a short pause, not always observed; (3) expiration; and (4) a considerable pause, occupying about one-fifth of the whole time required for one complete respiratory act. The act of expiration is always more prolonged than that of inspiration, the former being to the latter in the ratio of 12 : 10 in adult males, and as 14 : 10 in children, women, and aged persons. The number of respiratory acts performed in a minute varies at different ages. At birth there are 44 respirations in one minute; at 5 years of age, 26; from 15 to 20, 20; from 20 to 25, 18; from 25 to 30, 16; from 30 to 50,. 18: so that from 16 to 20 may be taken as the ordinary range for

healthy adults. The average ratio which the number of respirations bears to the number of heart-beats in a given time is about 1 : 4½, and if there be any great deviation from this ratio, there is probably some obstruction to the aeration of the blood, or some disorder of the nervous system.

179. CAPACITY OF THE LUNGS.—When the lungs have been emptied as much as possible of air by the most powerful expiratory effort, they still contain a quantity over which we have no control, and which may be estimated at about 100 cubic inches. To this portion of the contents of the lungs the term *residual air* is applied. In addition to this residual air, physiologists distinguish, in connection with the respiratory process, *supplemental air*, which is that portion which remains in the chest after an ordinary gentle expiration, but which may be displaced at will, 100 cubic inches; *breathing* or *tidal air*, which is the volume that is displaced by constant gentle inspiration and expiration, about 30 cubic inches; and *complemental air*, or the quantity which can be inhaled by the deepest possible inspiration, over and above that which is introduced in ordinary breathing, 100 cubic inches. The greatest volume of air that can be expelled by the most powerful expiration, which is obviously the sum of the supplemental, tidal, and complemental air, is designated as the *vital capacity*—in all, 230 cubic inches.

QUESTIONS.

172. What is the object of respiration?

173. Describe the arrangements in the lungs by which the air is brought into close proximity to the blood. Describe a minute lobule of the lung.

176. How much air passes in and out of the lungs of an adult man in one hour? What change is effected in the air by respiration? How is the capacity of the chest increased in inspiration?

177. What are the different types of breathing?

178. Give the number of respirations per minute at different ages.

179. How much air exists in the lungs of an adult man after the deepest possible inspiration and after the deepest possible expiration?

180. Abnormal Breathing.—There are three peculiar forms of abnormal, that is to say, of unnatural breathing: (*a*) *apnœa*. When the blood contains an excess of oxygen, respiratory movements either cease or become fewer in number. If we take several deep breaths, as before diving, we can 'hold the breath' for a longer time. (*b*) *dyspnœa*, or difficulty in breathing. This may arise in a variety of ways: (1) from puncture of the cavity of the pleura, preventing expansion of the lungs; (2) obstruction in the air-passages, preventing the free passage of air to and from the lungs, as in strangulation; (3) profuse bleeding, affecting the nervous mechanism of breathing; (4) anything that weakens the circulation; (5) anything that diminishes the extent of the respiratory surface, as in many diseases of the lungs; and (6) a deficient amount of oxygen in the air. If the respiratory process is entirely interrupted, as in choking, drowning, stoppage of the movements of breathing by pressure on the chest, as when one is wedged in a crowd, then we have (*c*) the state called *asphyxia*, the symptoms of which are produced by accumulation of carbonic acid in the blood. It is usually divided into three stages, all of which can be traced in death by drowning. (1) *First*, there is difficulty in breathing, or dyspnœa. The respiratory movements are hurried, irregular, and soon deeper and laboured; the inspiratory and expiratory muscles, more especially the former, contract powerfully, and the muscles of the thoracic and abdominal regions contract spasmodically. At the end of about *one minute*, the spasmodic movements extend more or less to the muscles of the extremities, chiefly affecting the flexors. During this period the oxygen is being used up, the blood is becoming more and more venous, and the respiratory centres in the *medulla oblongata* or *bulb* are excited by the venous blood; (2) *Second stage*.—The convulsions cease, and the movements of inspiration are scarcely perceptible,

while those of expiration come powerfully into action. The second stage also lasts about *one minute*, and its phenomena are due to the action of the highly venous blood on the *medulla oblongata* and the spinal cord ; (3) *Third stage.* —The pupils are now dilated ; the eyelids do not shut on touching the eyeball ; consciousness is abolished ; reflex movements cease ; the muscles become loose or flaccid ; and there is a state of calmness, which presents a striking contrast to what was observed a minute before. The ordinary inspiratory muscles act more feebly, and at longer intervals of time, whilst the accessory inspiratory muscles occasionally contract spasmodically, so as to produce a series of convulsive gasps ; similar convulsive movements now and then occur in the muscles of the extremities, more especially in the extensors, the head is bent backwards, and the body may also be arched in the same direction ; the nostrils are dilated ; the heart becomes paralysed, its right cavities are very distended with venous blood, which enfeebles the muscular tissue of the heart ; the pulse cannot be felt, and, after one or two convulsive movements, death ensues. This period lasts from *two to three minutes*, and the whole of the stages may be completed in *five or six minutes.* The heart, however, may beat for seven minutes. Recovery from asphyxia may take place if artificial respiration is set up *before* the heart ceases to beat. In cases of drowning, complete submersion for three or four minutes is fatal. Newly-born animals sustain immersion for a much longer time than adults. On examining the body, the venous system generally, the right cavities of the heart, and the capillaries of the lungs are found to be full of dark venous blood, whilst the arterial system is nearly empty, the elasticity of the great vessels having driven the blood onwards. The blood is very dark coloured, and its colouring matter is almost entirely in the form of reduced hæmoglobin—that is,

hæmoglobin from which the respiratory oxygen has been removed.

181. VENTILATION.—A knowledge of the respiratory process explains the benefit to be derived from ventilation. Ten thousand parts of ordinary atmospheric air contain from 2 to 4 parts of carbonic acid gas. If this gas be present to the extent of $1\frac{1}{2}$ to 3 parts in 1000, headache and giddiness are felt; and if it be increased to 20 parts in 1000, death will be the result. To secure a proper degree of dilution of carbonic acid in a room, so as to render the air fit for respiration, about 2000 cubic feet of fresh air should be introduced every hour for each person living in the room.

182. ESSENTIAL NATURE OF THE RESPIRATORY PROCESS. —Respiration may be divided into *external* and *internal* breathing. By *external breathing* we mean the interchange between the gases in the blood and the gases in the air introduced into the lungs by the arrangements above described. The venous blood comes to the lungs surcharged with carbonic acid gas, and containing too small an amount of oxygen. In the air-cells, on the other hand, we have a gas rich in oxygen, and containing relatively a much smaller amount of carbonic acid gas than exists in the blood. Carbonic acid gas thus escapes from the blood into the air-cells, and oxygen is taken into the blood. The oxygen taken in unites with the *hæmoglobin* in the red blood-corpuscles, *oxyhæmoglobin* being formed. Thus the blood is arterialised, having lost carbonic acid and having gained oxygen. The arterial blood then passes to the tissues, and here we come to the domain of *internal breathing*. All living tissues breathe—that is to say, they produce carbonic acid and consume oxygen. They must get rid of the excess of carbonic acid, otherwise it would act injuriously, and they must receive new supplies of oxygen. This is accomplished by the lymph and by the blood. The lymph, as already seen (p. 148), comes from the blood, bathing

each element of tissue, and internal breathing is the interchange between the gases of the blood and lymph and the gases of the tissues. The blood brings oxygen near to the tissue by the oxyhæmoglobin, the *oxygen-carrier;* the oxygen is given up to the lymph; from the lymph the tissue takes it up; the tissue produces carbonic acid; this it gives up to the lymph; and by the lymph it is passed back to the blood. The blood having lost oxygen and gained carbonic acid, is now venous, and it goes on to the lungs to again get rid of its excess of carbonic acid gas and receive a new supply of oxygen. Thus the pigment of the blood is the *oxygen-carrier*, and research has shown that the carbonates and phosphates of soda in the blood are the *carbonic acid carriers*.

QUESTIONS.

180. What are the three forms of abnormal breathing? Mention the various ways in which asphyxia may be brought about. Describe the stages of death by drowning.
181. State your reasons for asserting that a plentiful supply of fresh air is essential to life.
182. Distinguish external from internal breathing. What are the arrangements for the respiratory process in an active tissue, as in a muscle?

CHAPTER VIII.

NUTRITION AND SECRETION.

183. NUTRITION.—The tissues of the body, such as muscle, bone, nerve, or brain, are nourished by the blood. But as this fluid is almost the same in chemical composition in different parts of the body, and as the tissues differ much in this respect from each other, each tissue must have a *selective power*, whereby it selects from the blood the material it requires for its growth. To secure healthy nutrition, we must have (1) *an adequate supply of blood.* If any part

of the body be not supplied with abundance of blood, its actions are enfeebled; and if the supply be cut off altogether, it soon weakens and dies. (2) *The blood must also be healthy in quality.* If affected by disease of any organ, so that certain injurious materials are not eliminated, the general nutrition of the body speedily suffers. To secure proper nutrition, a part must (3) *be subject to the influence of the nervous system.* Disease of the spinal cord causes paralysis of the lower limbs, and the muscles become soft, flabby, and diminish in size. Section of a nerve supplying a part is often followed by destruction of the part by ulceration. Finally (4), *the part itself must be in a healthy condition* to secure proper growth. Any tissue which has acquired any peculiarity of structure by previous disease retains this peculiarity for many years; but in course of time the tissue tends to revert to its original condition. This explains such phenomena as the perpetuation of cicatrices and the influence of the vaccine virus. In the latter case, the virus stamps a peculiar quality on the blood and tissues, which modifies any subsequent attack of smallpox. *Growth* is dependent essentially on the supply of material to the tissues by the blood, and on the amount of waste of tissue. If the supply exceed the waste, as in childhood, the body increases in weight and power; if the supply and waste are equal, the body may remain in a stationary condition for many years, as in middle life; and if the supply be much less than the waste, the body loses weight and strength, as in old age.

184. SECRETION.—Secretion is that function by means of which certain fluids are separated from the blood for further service in the economy. Various of these secretions, such as the saliva, gastric juice, pancreatic juice, &c., have been already described, but here we may briefly refer to the process of secretion generally. However complicated the structure of the various secreting glands may be, it is

found on minute examination to consist of a delicate membrane, called a basement-membrane, having blood-vessels richly distributed under its attached surface, and actively growing cells on its free surface. By foldings and reduplications of these elements of structure, all secreting glands are formed (fig. 111). The *cells*, however, are the active agents. They select from the blood the materials necessary, and elaborate these to form the secretion. These cells may be directly influenced by the nervous system. The secretion is not directly formed from the living matter

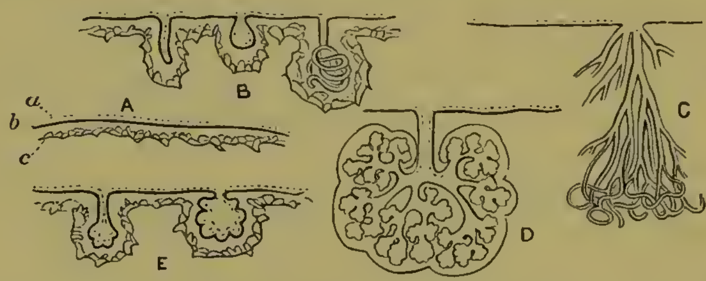


Fig. 111.—Diagram showing various forms of Secreting Structures :

A, general plan of a secreting membrane ; *b*, basement-membrane with cells, *a*, on one side, and blood-vessels, *c*, on the other ; B, simple *tubular* (gastric glands), *follicular* (tonsils), and *elongated tubular* or *convoluted* glands (sweat-glands) ; C, *compound tubular*, as in kidney ; D, *compound racemose*, as in salivary gland, pancreas, &c. ; E, *simple racemose*, two forms, as sebaceous glands, &c.

(protoplasm) of the secreting cell. Intermediate substances are formed, and some of the materials of the secretion may not be set free till the moment they leave the living cell. Thus cells that secrete mucus do not form mucus, containing mucin, at once ; there is an antecedent body, a mucin-producer, or, as it is called, *mucinogen*. Many, but not all, secreting cells are developed, grow, live a certain time, drop off from the membrane, and becoming ruptured, the secretion is set free. Thus secretion is not opposed to growth, as at one time supposed : it is dependent on the *growth of certain cells* (fig. 33).

QUESTIONS.

183. What do you understand by nutrition? What are the conditions of healthy nutrition?

184. Describe the structure of a secreting membrane. Draw a diagram showing the various types of glands.

CHAPTER IX.

THE KIDNEYS.

185. GENERAL DESCRIPTION.—The human kidneys are situated in the loins, one on each side of the spine (fig. 39). A well-developed healthy kidney weighs about six ounces. When cut open (see fig. 112), we find a cavity communicating with the *ureter*, U, the excretory duct of the kidney, and we observe also that the organ consists of two regions, which are named, from their position, the external or *cortical*, and the internal *medullary* or substance.

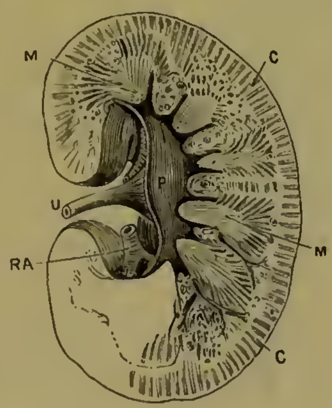


Fig. 112. — Longitudinal Section of Kidney:

C, cortical substance; M, medullary substance; P, pelvis; U, ureter; RA, renal artery.

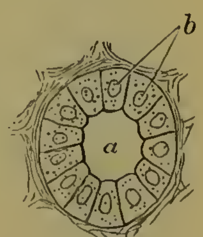


Fig. 113.—Section of a Uriniferous Tubule:

a, section of tube; *b*, epithelial cells.

The medullary part consists of straight tubules, which divide in twos as they pass outwards to the cortical part; while in the latter the tubes are extremely convoluted (fig. 114). The tubules are termed *tubuli uriniferi.* They are lined by irregularly shaped cells somewhat like those of columnar epithelium (fig. 113). In the cortical part of

an injected kidney there are numerous small round balls of capillaries called *Malpighian bodies*, after the celebrated anatomist who first observed them. In man they are about the $\frac{1}{100}$th of an inch in diameter. They consist of a mass of minute capillaries supplied with blood by an afferent vessel, and having also an efferent vessel to carry the blood away. Each of these little balls is embraced by

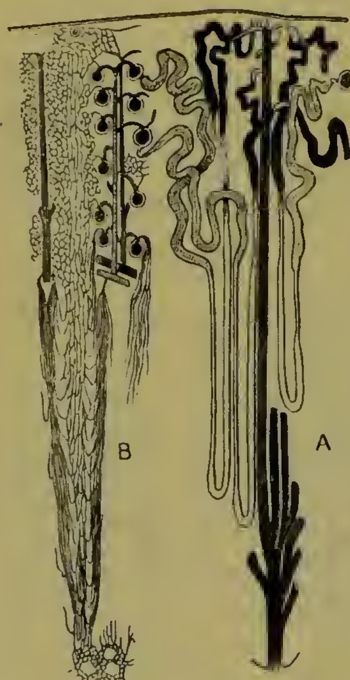


Fig. 114.—Diagrammatic View of Tubules, A, and Blood-vessels, B, of Kidney.

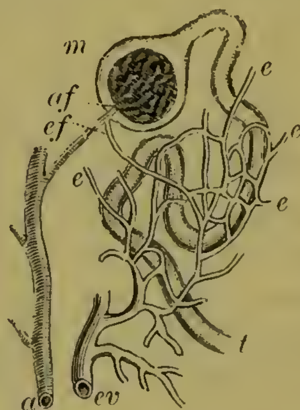


Fig. 115.—Arrangements connected with a Malpighian Body:

a, terminal branch of the artery, giving the terminal twig, *af*, to the Malpighian tuft, *m*, from which emerges the efferent vessel, *ef*. Other efferent vessels, *e*, *e*, *e*, are seen proceeding from other tufts, and entering the capillaries surrounding the uriniferous tube, *t*. From this plexus of capillaries the emulgent vein, *ev*, springs.

an infolding of the dilated end of one of the uriniferous tubes, forming the *capsule of Bowman*, as seen in fig. 115. The watery part of the urine is here separated from the blood, while the solid matter is excreted by the action of the cells lining the tubules.

186. Special Points in Structure.—These are well seen in fig. 114. At B we may observe straight arterial vessels

springing from arched vessels just at the junction of the cortical with the medullary portions. The straight vessels run towards the surface of the kidney, and give off the *afferent* twigs to the Malpighian bodies. The *efferent* vessels are seen breaking up into a second set of fine capillaries (fig. 115), from which the veins originate. Observe also the capsule surrounding the end of the tubule, the convoluted part of the tube, then a long tube that runs down into the medullary part, and then returns to the cortical part, to end in the straight discharging tubes seen very black at A. The loop is called the *looped tube of Henle.*

187. Characters of the Urinary Secretion.—Urine is a clear, amber-coloured, faintly acid fluid, with a bitterish taste, and an aromatic odour. It has a specific gravity of about 1020. It contains (1) water; (2) a small amount of mucus from passages; (3) urea, from the oxidation of nitrogenous matter; (4) uric acid, in the form of urates of soda and potash; (5) a number of less oxidised bodies in small quantities, such as allantoin, xanthin, kreatinin, &c.; (6) colouring matter; (7) odoriferous matter; (8) salts, chiefly chlorides of sodium and potassium, sulphates of soda and potash, phosphates of soda and potash, phosphate of lime, and phosphate of magnesia; (9) a trace of sugar; and (10) small quantities of the gases oxygen, carbonic acid, and nitrogen. In flesh-eating animals, urea is present in large amount; very little uric acid being found; but in the urine of vegetable feeders, little urea and no uric acid are present, while *hippuric* acid exists in considerable amount.

188. Mode of Action of the Kidney.—The true secreting part of the kidney is the epithelium lining the convoluted tubules. The water and saline matters pass through the thin walls of the vessels forming the glomerulus of Malpighi, and thus enter the convoluted tubes. The process by which water and saline matters are separated is scarcely a filtrative process, as the cells lining Bowman's

capsule exert a selective action. The fluid thus formed contains an excess of water, and part of this excess is absorbed into lymphatics from the tube forming the loops of Henle, and thus re-enters the blood.

189. QUANTITY OF URINARY CONSTITUENTS.—One hundred parts of urine passed by a healthy person contain of water 96, and of solids 4 per cent. The solids are partly organic and partly inorganic. Of the *organic* solids, the percentages are urea 2·8, uric acid ·05, and kreatinin ·1. There are also traces of xanthin, hypoxanthin, oxaluric acid, hippuric acid, and oxalic acid. The pigment urobilin is present only in very small amount, and sometimes there may be a trace of indican. Of the *inorganic* substances, the chief is chloride of sodium, about 1·5 per cent.; of phosphoric acid, about ·16 per cent., united partly to alkalies, chiefly sodium, and alkaline earths—namely, magnesia and lime. There are also small quantities of sulphates. In twenty-four hours we may have eliminated, in grains, of urea 480, uric acid 7·5, of common salt 300, and of phosphoric acid 30 to 40.

190. CONDITIONS INFLUENCING THE AMOUNT OF URINE. —The normal amount is from 50 to 60 ounces daily, containing 1½ ounce of solids. It is less in summer than in winter. The amount seems to depend (1) on the intensity of the pressure of the blood within the Malpighian tufts; (2) on the activity of the secreting cells; and (3) on the quantity of water or other diffusible matter taken into the system.

191. SEPARATION AND DISCHARGE OF THE URINE.—The urine is constantly being secreted by the kidney. It is carried away to the *bladder* by a tube called the *ureter*—the bladder serving as a reservoir (fig. 39). It collects in the bladder until that organ is completely filled, when it is voided by contraction of the walls of the bladder, aided by the abdominal muscles. The evacuation is partly voluntary and partly involuntary.

QUESTIONS.

185. Describe the naked eye appearances of a section of a kidney.
186. Describe the circulation in the kidney.

187. Enumerate the chief constituents of the urine.
188. How do you think the urine is formed?
189. How much of each of the chief constituents of the urine is eliminated daily?

CHAPTER X.

THE SKIN.

192. GENERAL DESCRIPTION.—This organ, continuous at various points with the internal mucous surfaces, covers the whole body, and consists of two layers: first, a hard epithelium, composed of cells more or less flattened, called the *epidermis* (figs. 116, *a*, and 117, *b*); and second, of the *dermis*, *cutis vera*, or true skin, *c*, which is formed of connective and elastic tissue. Underneath the true skin we find a layer of fat, *g*. The surface of the true skin is raised into a series of papillæ, *b*, connected with the sense of touch. We find in the skin two kinds of glands. The *sudoriparous* or sweat glands consist of a tube, coiled into a ball at the deeper

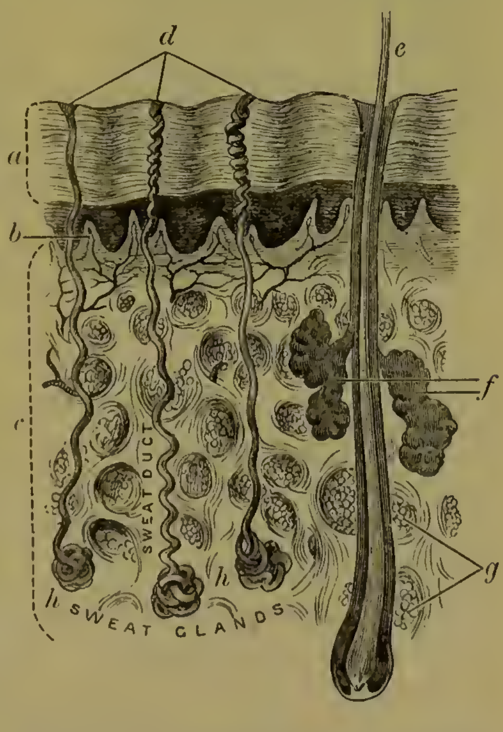


Fig. 116.—Vertical Section of the Skin: *a*, epidermis; *b*, papillæ; *c*, dermis, or true skin; *d*, sweat-pores; *e*, hair; *f*, sebaceous glands; *g*, fat-cells; *h*, sweat-glands.

part, and communicating with the surface by a spiral duct (fig. 116, *h*). The *sebaceous* glands are small racemose glands, which usually open into the hair-follicles (fig. 116, *f*), and secrete an oily fluid for lubricating the hairs and surface of the skin.

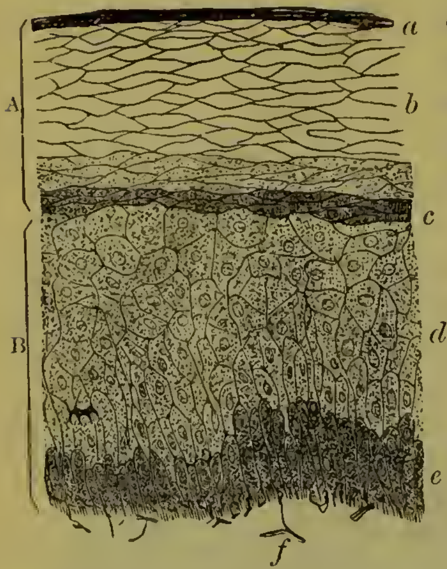


Fig. 117.—Section of Epidermis from the Human Hand, highly magnified :

A, horny layer, consisting of *a*, superficial horny scales ; *b*, swollen out horny cells ; *c*, stratum lucidum : B, rete mucosum, consisting of *d*, prickle cells ; *e*, elongated cells near corium ; *f*, a nerve-fibre.

193. Secretion of Sweat.—The chief excretion of the skin is *sweat*, an acid watery fluid (having a small amount of salts, chiefly chloride of sodium, and a trace of organic matter, chiefly urea, in solution), which is usually carried off from the surface in the form of vapour. The amount varies greatly : from five pounds in the twenty-four hours, to one pound. That the separation of this excretion is important, is proved by the fact, that if the skin be varnished over, so as to prevent exhalation, death speedily ensues. All the various modifications of epidermis, such as hair, horn, nail, hoof, feathers, &c., may also be regarded in the light of excretions.

194. Functions of the Skin.—The skin is (1) a protective covering for the parts underneath ; (2) an organ of excretion—separating sweat and sebaceous matter ; (3) an organ concerned in certain parts with the senses of *touch* and *temperature ;* and (4) partially as an absorptive and respiratory organ, absorbing small quantities of aqueous vapour, and giving off carbonic acid.

QUESTIONS.

192. Describe a vertical section of the skin. Describe the structure of the epidermis (see fig. 117).
193. What is sweat?
194. Enumerate the functions of the skin.

CHAPTER XI.

ANIMAL HEAT.

195. All the processes hitherto described, whether physical or chemical, contribute to produce heat. The great source of heat in the body is the oxidation processes which take place in almost every tissue and in every organ. The circulating blood acts as a conductor or distributer of heat, so that the uniform temperature, taken in a partially protected place like the armpit (axilla), is about 98·4° Fahr. In the mouth and rectum the temperature may be about one degree higher. These matters have already been discussed in treating of the body in action (see p. 65). Animals, such as man, which maintain a constant temperature, are called *warm-blooded,* while those which have no constant temperature, and have a temperature usually only a few degrees above that of the medium in which they live, are called *cold-blooded.* The body is always losing heat by *radiation* and *conduction.* To maintain the body at a uniform temperature, whatever that of the outside medium may be, arrangements are made by which the amount of heat eliminated and the amount of heat produced are kept at a balance. So-called warm-blooded creatures have arrangements for the regulation of temperature by which an equilibrium is maintained between the amount of heat lost by the body and the amount of heat liberated in the body; while cold-blooded animals have no such arrangements. Thus by the use of clothes, by the

activity of the skin, by the nature of the food, and by the amount of muscular exertion, the heat is maintained and regulated.

QUESTIONS.

195. What is the temperature of the body in the armpit? Suppose a man were exposed naked on a cold day, would his temperature fall much, and if not, why not? How would a frog's temperature vary suppose it were taken into a warm room?

CHAPTER XII.

ANIMAL MECHANICS.

196. Having already described the bones, joints, and muscles, we now proceed to discuss briefly the mechanical arrangements met with in the body, or the physiology of movement (see also p. 25, par. 11).

197. MECHANICAL ARRANGEMENTS OF MUSCLES.—The great majority of the muscles of the body are attached to levers formed by the bones. Here the movable bone represents a lever of which the *fulcrum* is the articulation with the fixed bone, the *power* is employed at the point of insertion of the contracting muscle, and the *resistance* may be of various kinds according to the obstacles which tend to prevent displacement of the movable bone (fig. 25). In the body we find examples of levers of the first, of the second, and of the third order.

198. LEVERS OF THE FIRST ORDER.—Here we find the fulcrum between the power and the resistance. As an example, take the balancing of the head on the vertebral column (fig. 2): the fulcrum is the articulation between the occipital bone and the atlas; the resistance is the weight of that part of the head and face in front of the articulation; and the power is applied behind at the point of insertion of the muscles of the neck. The construction of the vertebral column, the balancing of the trunk on the pelvis, and of the

leg on the foot, represent levers of the same kind. Usually, in man, this order of lever is for the purpose of *stability*, but we find it also in certain movements. For example, in extending the fore-arm upon the arm—the fulcrum is the elbow-joint, the power applied behind the articulation is the insertion of the triceps, and the resistance is the weight of the fore-arm in front of the articulation (fig. 27, *d*).

199. LEVERS OF THE SECOND ORDER.—Here the resistance is between the power and the fulcrum. In this lever the power-arm * is always longer than the resistance-arm. As the forces are inversely proportional to the length of the arms of the lever, a comparatively weak force will overcome considerable resistance, and consequently this lever is advantageous as regards expenditure of force. But it is disadvantageous as regards rapidity of movement, for the displacements of the two points of application are proportional to the lengths of the arms of the lever. For example, if the length of the power-arm = 10 feet, and that of the resistance-arm = 1 foot, a force of one pound would move a resistance of ten pounds, but the point of application of the power would move through ten feet, while that of the resistance would be displaced only one foot. This lever may be termed the lever of *power*. It is not common in the body. As an example, take the action of standing on tiptoe. Here the fulcrum is the contact of the toes with the ground; the power is at the insertion of the tendo Achillis, the strong ligament fixed into the *os calcis*, or heel-bone; and the resistance is the weight of the body transmitted to the articulation between the tibia and astragalus (fig. 22).

200. LEVERS OF THE THIRD ORDER.—The power is between the resistance and the fulcrum. In this lever the

* The term *arms of the lever* is the distance which separates the fulcrum from the point of application of the power or of the resistance. The one may be called the *power-arm* and the other the *resistance-arm*.

resistance-arm is always longer than the power-arm, and while it is advantageous as regards swiftness, it is disadvantageous as regards expenditure of force. It may be termed the lever of *rapidity*. It is the one common in the movements of man. For instance, in the flexion of the fore-arm upon the arm, the fulcrum is the articulation at the elbow; the power is at the insertion of the flexors (*brachialis anticus*, and *biceps*), and the resistance is the weight of the fore-arm. The power is usually applied in the body near the fulcrum, and the power-arm is thus much shorter than the resistance-arm, and hence only small weights can be moved, but with great speed. Thus the various movements of the body are rapidly performed, and the clumsy form of the limb which would have resulted had the power been applied near the resistance is obviated (fig. 25).

Simple movements such as are above described rarely take place. Usually the movements which one bone makes on another are not effected by one muscle, but by several, which may be regarded as associated together for that movement. Thus, in moving the arm, say from pronation to supination with a slight degree of flexion or extension, many muscles act (fig. 26).

201. CONDITIONS OF EQUILIBRIUM IN THE BODY.—*Posture.*—In the natural erect posture, the human body becomes a rigid pillar without almost any muscular effort—the conditions being that the centre of gravity is supported within the base or surface between the points of contact of the soles of the feet with the floor. The centre of gravity of the head is in front of its point of support on the atlas, but the arrangements are such as to secure equilibrium chiefly by the action of the ligaments which bind the occipital bone to the atlas and axis. When the slight muscular effort required is withdrawn, as during sleep, the head droops forwards, and the chin rests on the chest. According to Weber, the centre of gravity of the trunk is situated in front of the tenth dorsal vertebra, and

a plumb-line dropped from it passes behind a line connecting the two hip-joints, so that the trunk would tend to fall backwards were it not attached anteriorly by a firm ligament to the femur. The centre of gravity of the whole body lies immediately in front of the prominence of the sacrum (figs. 1 and 2), and a line suspended from it would pass a little in front of a line connecting the axes of both ankle-joints, so that the body has a tendency to fall forwards. This is prevented partly by the wedging of the astragali into the fork-like cavities formed by the lower ends of the tibia and fibula (fig. 20), and partly by the action of the muscles forming the calf of the leg. As already pointed out (p. 25), the weight of the body falls upon an arch formed by the bones of the foot. When standing in the rigidly erect position, like that of a soldier at 'attention,' the muscles on the anterior aspect of the body and limbs act slightly, so as to prevent the body from falling backwards, while those on the posterior aspect prevent it from falling forwards (fig. 118). In sitting, the trunk rests on the *tuber ischii* (see fig. 18, *c*), and tends to swing forwards and backwards on these. Thus there is an anterior and a posterior sitting posture.

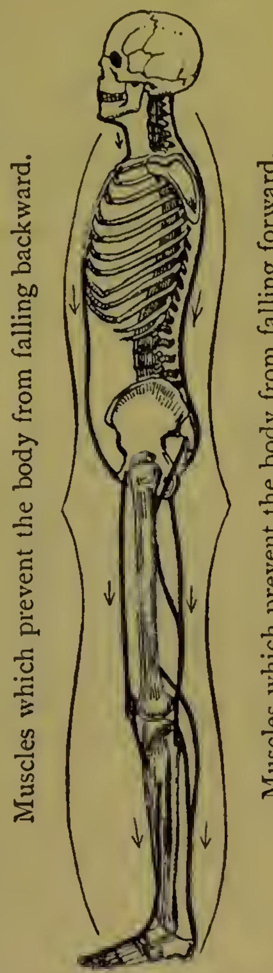


Fig. 118.
Muscles which maintain the erect posture.

202. *Locomotion.* — In walking, the pelvis is alternately supported by one of the legs. Starting, for example, with the right leg, the body is inclined forwards, the right foot raised, the right leg advanced, and the foot put on the ground. Then the left heel is raised, but the toes of the left foot have not quitted the ground when the right foot has reached it, so that both feet are never off the ground at the same moment. The action of the muscles of the left leg moves the body forwards,

upwards, and to the right side. When the left foot has left the ground, the body is supported on the right leg, and the left leg swings forward like a pendulum to a position in advance of the right foot, constituting the second step. Rapidity of walking depends on the length of the step and the duration of the step, or the pendulum-oscillation of the leg. The pendulum-oscillation is the quicker the shorter the leg, hence the step of short-legged persons is quicker than that of long-legged ones. In running, the action is more like that of a series of jumps—that is to say, there are intervals in the step during which *both* feet are off the ground at once. At the commencement of the step in running, the active leg is strongly flexed, and then it is extended with a kind of sudden jerk.

Questions.

197. Describe a lever.
198. Give an example of a lever of the first order; (199) of the second order; and (200) of the third order, stating the position of the fulcrum in each case.
199. What advantage is gained by the insertion of the tendon of the biceps near the elbow-joint?
201. Describe the arrangements for the maintenance of the erect posture *without* fatigue. Why may we become fatigued if we are kept at 'attention' for a long time?
202. Describe ordinary walking.

CHAPTER XIII.

THE SENSES.

203. Introduction.—The senses are called into play when the condition of the body has been affected to a certain degree by external or internal agencies. A flash of light, a sound, a touch, may so act upon the body as to be followed by a *sensation* or mental state. Sensitiveness is a property of all animals, and possibly of not a few plants. Some animals, indeed, are so low in the scale of organisation as to have no special parts set aside for the reception of

sensory impressions, but every part of their body seems alike fitted to recognise changes in its surroundings. As soon, however, as we pass to the higher grades of animal life, as in man, we find certain parts or organs of sense whose duty it is to keep the body in relation to its surroundings, and also a nervous system which receives impressions and ensures the co-operation of all the individual elements of the body one with another.

In order that sensations may be felt, we have a *central nervous system*, or *sensorium*, from which nerve-fibres pass outwards to all parts of the body, and at the ends of the nerve-fibres certain structures or *terminal organs*, which are so formed as to be capable of responding to some special variety of impression. Thus the terminal organ of the nerve of vision is insensitive to the vibrations which, by acting upon the ear, originate changes leading to the sensation of sound. The sensorium does not act as a whole, but is differentiated so that one part is devoted to one sense, another to another; and when the nerves which lead to these nerve-centres have been stimulated, it matters not what the nature of the stimulus to the nerve has been, the sensation experienced is always for each centre of one and the same kind. Thus the visual centre always gives rise to the sensation of seeing something, the auditory centre to that of hearing, the olfactory centre to sensations of smell, the gustatory centre to those of taste, and the tactile centre to touch. But, over and above these special forms of sensation, there are many vague or general sensations, such as those of heat or cold, of pain or fatigue, of pressure, resistance, and the like, which may seem to be felt in almost every part of the body; and although each of these has in all probability its special nerve-centre, yet no special terminal organ seems to be necessary.

Special *terminal organs*, then, are developed for the senses of sight, hearing, smell, taste, and touch.

Touch.

204. General.—The sense of touch, including that of different degrees of heat, is possessed by the skin, by the walls of the mouth and nostrils, and by the tongue, but it is most highly developed on the tips of the fingers. The essential organs of this sense are the true skin, containing capillaries, and the terminations of sensory nerves. On examining the surface of the true skin by a magnifying-glass, we can see a regular arrangement of papillæ, or cone-like projections, about $\frac{1}{100}$th of an inch in length (fig. 116). In many of these papillæ there are found small, round or oval bodies made of hard fibrous tissue, having a nerve-fibre coiled round them, and sometimes penetrating into their interior. These are called *touch-bodies* (fig. 119). They serve as resisting structures against which the nerve may be pressed, and thus the sense of touch may be intensified. The touch-corpuscles are the chief terminal structures connected with the sense, but there are others. At the margins of the lips, and in other localities where the sense is very delicate, we find small bladder-like bodies, having nerve-fibres passing into their interior. These have been called *end-bulbs.* Again, in the tissue below the skin in the palm of the hand and fingers and the soles of the feet there are other corpuscles, larger than either the touch-corpuscles or the end-bulbs, each consisting of a number of folds, like the coats of an onion, surrounding a core into which a nerve-fibre passes. These

Fig. 119.—Touch-corpuscle: *a*, layers of connective tissue of the true skin; *b*, body of corpuscle; *d*, *d*, nerve-fibres twisted spirally round the corpuscle; *c*, nerve-fibres at the lower end of the corpuscle; *e*, nerve-fibre ending in little thickenings near the upper end of the corpuscle. Magnified 250 diameters.

are the *Pacinian bodies.* Hairs also may be regarded as organs of touch, since nerves are connected with the roots or the bulbs. When one of these nerves is pressed upon by the contact of any foreign body, an impulse is produced which travels to the brain, whereby we become conscious of the impression. This consciousness, however, we refer not to the brain, but to the part affected ; a subjective power, which is the result of experience, inherited and acquired.

Fig. 120.
Compasses of Weber, or æsthesiometer.

205. NATURE OF TOUCH.—A sensation of touch is produced by gentle pressure. The most delicate contact causes pressure. It is a familiar observation that all parts of the skin are not equally sensitive. The method of determining the degree of sensitiveness, first employed by Weber, consists in finding the smallest distance at which the two points of a pair of compasses can be felt. The results in millimetres* are given in the following table:

Tip of tongue	1·1	Back, eyelid	11·3
Under surface of third phalanx of finger	2–2·3	Under surface of lower third of fore-arm	15·0
Red part of the lip	4·5	Cheek	15·8
Under surface of second phalanx of finger	4–4·5	Temples and Forehead	22·6
Upper surface of third phalanx of finger, tip of nose	6·8	Back of head	27·1
Ball of thumb	6·5–7	Back of hand	31·6
Centre of palm	8–9	Knee	36·1
Under surface of third phalanx of great toe	11·3	Fore-arm and leg	45·1
Upper surface of second phalanx of finger	11·3	Back, opposite fifth dorsal vertebra	51·1
		Neck	54·1
		Upper-arm, thigh, centre of back	67·1

* 1 millimetre = $\frac{1}{25}$ of an inch.

206. Sensations of Temperature.—The skin is the chief organ by which we appreciate temperature. Sensations of heat and cold can also be excited in mucous surfaces. Direct irritation of a nerve does not give rise to these sensations. Thus if we plunge the elbow into very hot water, or into ice-cold water, we do not experience heat or cold by thus irritating the ulnar nerve, which lies here just below the skin, but there is a painful sensation referred to the extremities of the nerve. Recent observations show that there are minute areas of skin in which sensations of heat and cold may be more acutely felt than in adjoining areas. Some of these areas are more sensitive to cold, and hence are called *cold spots;* while others, more sensitive to heat, have received the name of *hot spots;* and they appear to be, or to contain, end-organs, arranged in points, subservient to a temperature-sense. A topographical view of such spots on the radial half of the dorsal surface of the wrist is shown in fig. 121. A simple method of demonstrating this curious phenomenon is to use a solid cylinder of copper, say eight inches in length by $\frac{1}{2}$ inch in thickness, and sharpened at one end to a fine pencil-like point. Dip the pointed end into hot water, close the eyes and touch parts of the skin. When a hot spot is touched, there is an acute sensation of burning. Such a spot is often near a hair. Again, in another set of experiments, dip the copper pencil into ice-cold water and search for the cold spots. When one of these is touched, a curious sensation of cold, as if gathered to a point, is experienced. It will be found, in this way, that in a given area of skin

Fig. 121.
C, cold spots ; H, hot spots.

there may be hot spots, cold spots, and tactile spots. Cold spots are more abundant than hot spots. The spots are arranged in curved lines, but the curve uniting a number of cold spots does not coincide with the curve forming a chain of hot spots.

Questions.

203. What do you mean by sensitiveness and sensation? What are the parts necessary for a sensation?
204. Describe the various kinds of tactile bodies.
205. How may tactile sensibility be measured? Where are the most sensitive portions of the skin?
206. What evidence is there that we can appreciate heat and cold by the skin, say of the forefinger?

Taste.

207. General.—The organs of taste are in the mucous membrane of the tongue, especially at its back part. The nerves of taste are the lingual branch of the fifth cranial nerve and the glosso-pharyngeal, the former supplying the

Fig. 122.—Organ of Taste from Tongue of Rabbit:

a, section through *taste-organ*, showing flask-shaped bodies in the depressions; *b*, flask body isolated, showing that it is made of spindle-shaped cells; *c*, small cells found in flask, having pointed lower ends which are continuous with nerve-fibres; *d*, fusiform cells which form wall of flask-shaped body.

anterior two-thirds, and the latter the posterior one-third of the tongue. The *chorda tympani*, a branch of the facial, is also a nerve of taste for the tip of the tongue. The mucous membrane of the tongue presents papillæ of various forms, known as *filiform*, or thread-like; *fungiform*,

or mushroom-like; and *circumvallate.* The circumvallate papillæ are from thirteen to fifteen in number, and are set in the form of a V with its point backwards. Each resembles a broad fungiform papilla surrounded by a trench. The terminal organs of taste are flask-shaped bodies, well seen in the tongue of the rabbit (fig. 122), and abounding in the circumvallate papillæ. They derive their nerves chiefly from the glosso-pharyngeal nerve. The contact of a sapid body with the surface of the tongue is not sufficient to evoke the sense of taste. The substance must be dissolved, and to effect its solution a special fluid is provided—the saliva. In febrile diseases, in which the tongue is dry and coated, the sense of taste is either dormant or perverted. Taste is more acute in some persons than in others.

208. Physiological Conditions of Taste. — The tongue is the seat of sensations that are quite unlike each other. Thus, there are tactile sensations, as when we touch the organ with a pin, sensations of pressure, sensations of heat and of cold, burning or acrid sensations, peculiar sensations excited by the application to the tongue of an interrupted electrical current, and, lastly, sensations of true tastes. We must also distinguish from these sensations that are called *flavours*, experienced when we bring the tongue into contact with an onion or a savoury bit of cooked meat or fish. These are in reality sensations compounded of smells and tastes, and the sensation of tasting an onion is thus quite changed when we hold the nose and avoid breathing. True tastes may be classified as *sweet*, *bitter*, *salt*, *sour*, *alkaline*, and, perhaps, *metallic.* All of these are specifically distinct sensations, and they are no doubt due to some kind of action, probably chemical, which the substance excites in the taste-cells. If we assume that the taste-cells are connected with the ends of the nerves, then we can imagine that the chemical changes

excited in the taste-cells set up nerve impulses which, propagated to the centre of taste in the brain, give rise there to molecular changes that in turn are related to consciousness.

QUESTIONS.

207. What are the nerves of the tongue? Describe the papillæ on the surface of the tongue.

208. What sensations may be referred to the tongue?

Smell.

209. GENERAL.—The organ of the sense of smell is the

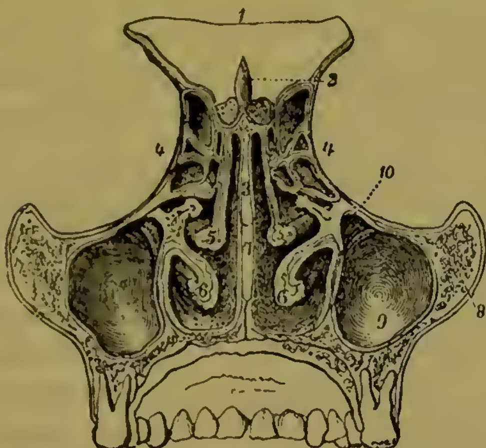


Fig. 123.—Transverse vertical section across the nasal cavities, opposite to the middle of the hard palate; the anterior part of the section seen from behind:

1, part of inner surface of cranium; 2, projection between the two cribriform plates of the ethmoid bone; 3, median septum or partition in the ethmoid bone; 4, 4, cells in the lateral masses of the ethmoid bone; 5, 5, the middle turbinated portion of the ethmoid bone; 6, 6, the two turbinated bones; 7, the vomer, or bony septum or partition, of the nose; 8, section of the malar or cheek hone; 9, a large sinus or space in the superior maxillary bone—sometimes called the maxillary sinus, or antrum of Highmore; it communicates with the nasal cavity, at 10, and there is a corresponding space on the other side.

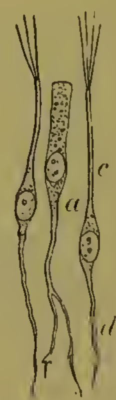


Fig. 124.

Cells from the olfactory organ, of two kinds:

a, with broad ends like knife-handles; *c*, with delicate pointed ends, and continuous with nerve-fibre at *d*.

mucous membrane lining a part of the nasal cavities

supplied with nerves from the *olfactory* bulbs or first pair of cranial nerves. Attached to the side walls of each nasal cavity are two delicate scroll-like bones, called *turbinated bones* (see fig. 123), which to a great extent divide each cavity into three spaces, lying one above the other (fig. 123). The upper two of these constitute the true olfactory chambers, while the lowest passage is merely used for respiratory purposes. The whole of this bony framework is covered by moist mucous membrane, covered by elongated cells attached to the ramifications of the olfactory nerves (fig. 124). By the contact of certain substances with these, a sensation of smell is produced. All odorous substances are in general such as can be readily acted on by oxygen. Animal effluvia exist near the soil, hence the bloodhound runs with his nose to the ground. The sense of smell is extremely delicate in most individuals. It is soon blunted, and consequently many who live among disagreeable odours do not perceive them. A distinction must be drawn between a smell proper, like that of a violet, and the irritation produced by the fumes of ammonia. The close stuffy sensation experienced on entering an ill-ventilated crowded apartment, is due partly to interference with the free play of respiration, and partly to the odour of certain organic matters given off by the breath.

210. Physical Causes of Smell.—Substances that excite the sense of smell must exist in the atmosphere in a state of fine subdivision, and even vapours and gases may be supposed to consist of minute molecules of matter. If air conveying an odour be passed through a long glass tube packed firmly with cotton-wool, it will still be odorous, although this proceeding will remove all particles larger than the one-hundred-thousandth of an inch. Again, a grain of musk will for years communicate its odour to the air of a room, and at the end of the time it will not have appreciably diminished in weight. Odoriferous particles

will mix with the air either in accordance with the laws of diffusion of gases or by virtue of their volatility, that is, the rapidity with which they evaporate. In the case of odorous gases, no doubt mixture takes place by diffusion, but an odorous essential oil will give off particles by a kind of evaporation.

211. Physiological Conditions of Smell.—The air containing the odour must be driven against the membrane. The nostrils may be filled with an odoriferous substance like eau-de-cologne, or air impregnated with sulphuretted hydrogen, and no smell will be experienced if no inspiration is made. When we make a sniff, the air in the nasal passages is rarefied, and as the odour-bearing air rushes in to equilibrate the pressure, it is forcibly driven against the olfactory surface. Odorous air passing from the posterior nares also gives rise to sensation of smell, although not so intense as when it passes in the normal direction. An odour may be perceived even although the nostrils are full of fluid.

Questions.

209. Describe a vertical section through the middle of the nose, and indicate where the sense of smell is located. Describe the terminal organ of smell.
210. What are the physical causes of odours?
211. Given an odoriferous substance, what is necessary to excite smell?

Sight or Vision.

212. General.—The sensation of light results from the influence produced indirectly on the expansion of the filaments of the optic nerve by vibrations of a delicate and subtle substance known as the 'ether.' But the falling of light upon the optic nerve itself will produce no sensation. An intermediary apparatus is necessary—the *retina*, which is an expansion of nervous matter intimately con-

nected with or related to the terminal filaments of the optic nerve. The action of light on the retina is analogous to that produced on a photographic surface, and it is associated with a change in the electrical condition of the retina.

213. General Description of Eye.—The *globe of the eye* is placed in the anterior part of the orbit, in which it is held in position by its connection with the optic nerve

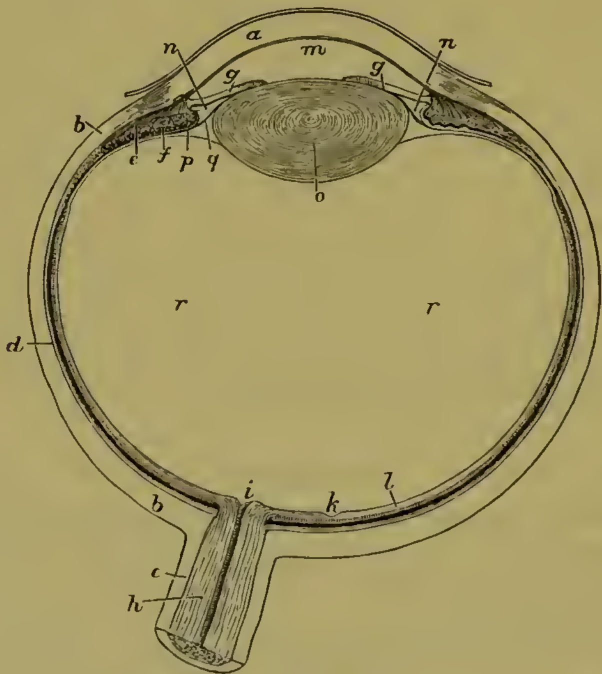


Fig. 125.

View of lower half of right Human Eye, divided horizontally :

a, cornea ; *b*, sclerotic ; *c*, sheath of optic nerve passing into sclerotic ; *d*, choroid ; *e*, ciliary muscle ; *f*, ciliary process ; *g*, iris ; *h*, optic nerve with artery in centre ; *i*, passage of nerve into retina, called optic disc or papilla ; *k*, fovea centralis in centre of yellow spot ; *l*, retina ; *m*, anterior chamber of aqueous humour ; *n*, posterior chamber of aqueous humour ; *o*, crystalline lens ; *p*, zonule of Zinn ; *q*, suspensory ligament of lens ; *r*, vitreous humour.

posteriorly, and with the muscles which surround it, and by the eyelids in front. It is further supported behind and on the sides by a quantity of fat. The eyeball is composed

of several investing membranes, and of certain transparent structures, which are enclosed within them. These transparent structures act as refractive media of different densities, so that rays of light entering the eye are so bent as to come to a focus on the retina. As rays of light may be supposed to emanate from the surface of any external object, a distinct image is formed. These refractive structures are, from before backwards—1st, the cornea, a transparent epidermic structure (fig. 125, *a*); 2d, the aqueous humour in the anterior chamber, *m*; 3d, the lens, composed of numerous laminæ, like the folds of an onion, *o*; and lastly, the vitreous humour, a jelly-like structure, *r*.

214. The outermost coat of the eye is the *sclerotic*, *b*. It is a strong, dense, white, fibrous structure. Posteriorly, it is perforated by the optic nerve. This coat, by its great strength and comparatively unyielding structure, maintains the inclosed parts in their proper form, and serves to protect them from external injuries.

215. The *choroid coat*, *d*, is a dark-coloured vascular membrane, containing pigment cells (see fig. 50). In front, it ends in the *ciliary processes*, *f*, which consist of about sixty or seventy radiating folds. These fit into depressions in the suspensory ligament of the lens, *q*, and assist in keeping it in its proper position.

216. The *iris*, *g*, may be regarded as a process of the choroid, with which it is continuous. It is a thin, flat curtain, hanging vertically in the aqueous humour in front of the lens, and perforated by the pupil for the transmission of light. It is composed of unstriped muscular fibres, one set of which being arranged circularly round the pupil, when necessary, effect its contraction; while another set lie in a radiating direction from within outwards, and by their action dilate the pupil. Thus more or less light may be admitted into the eye, and the function of

the iris is like that of the diaphragm in many optical instruments.

217. The varieties of colour in the eyes of different individuals and of different kinds of animals mainly depend upon the amount of the pigment which is deposited in the cells in the substance of the iris, and upon the thickness and degree of translucency of the iris.

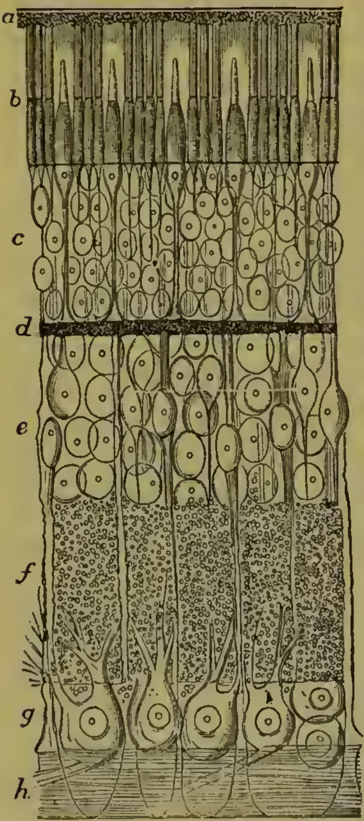


Fig. 126.—Diagrammatic Section of Human Retina: *a*, layer of hexagonal pigmented cells; *b*, layer of rods and cones (Jacob's membrane); *c*, external granules layer, with oval granules; *d*, external reticular layer of fine fibrils; *e*, internal granular layer; *f*, internal reticular layer; *g*, nerve-cells; *h*, fibres of optic nerve.

218. Within the choroid is the *retina* (fig. 125, *l*). With the naked eye it is seen to be a delicate semi-transparent sheet of nervous matter, lying immediately behind the vitreous humour, and extending from the entrance of the optic nerve nearly as far as the lens. On examining the retina at the back of the eye by an instrument called an *ophthalmoscope*, we observe, directly in a line with the axis of the globe, a circular yellow spot called, after its discoverer, the *yellow spot* of Sömmering, *k*. The only mammals in which it exists are man and the monkey. It is the point of distinct vision. When we read a book, we run the eye along the lines so as to bring portions of the lines successively on the yellow spot. If, on the other hand, we carefully fix our attention on a word in the middle of the line, we see that word distinctly, because its image is on the yellow spot; while the images of the words towards

each end of the line are less distinct, being on other and less sensitive portions of the retina.

219. The structure of the retina, as revealed by the microscope, is seen in fig. 126. It is now well known that the part affected by light is the layer of rods and cones next the choroid, so that a ray of light passes through all the other layers ere it reaches this sensitive layer. Each rod or cone is probably in direct communication with a filament of the optic nerve, so that, when excited by light, an impulse is transmitted along this filament to the brain, and the consequence is a luminous impression.

220. The TRANSPARENT MEDIA through which rays of light must pass before they form on the retina the images of external objects are :

(1) Immediately behind the transparent cornea is the *aqueous humour*, which fills up the chamber between the cornea and the lens (fig. 125, *m*). It is nearly pure water, with a trace of chloride of sodium.

(2) The *crystalline lens* lies opposite to and behind the pupil, close to the iris, and its posterior surface is received into a depression on the fore-part of the vitreous humour (fig. 125, *o*). In form it is a double convex lens, with surfaces of unequal curvature, the posterior being the more convex, and the curvature is also less at the centre than towards the margin.

(3) The *vitreous humour* lies in the concavity of the retina, and occupies four-fifths of the eye posteriorly (fig. 125, *r*).

221. The APPENDAGES of the eye are :

(1) The *muscles* by which the eye is moved are four straight (or *recti*) muscles, and two oblique (the superior and inferior). By the duly associated action of these muscles, the eye is enabled to move through a considerable range without the head being moved.

(2) The *eyelids* are two thin movable folds placed in front

of the eye, to shield it from too strong light, and to protect its anterior surface. The eyelashes intercept the entrance of foreign particles directed against the eye, and assist in shading that organ from an excess of light.

(3) The *lachrymal apparatus* consists of the lachrymal gland, by which the tears are secreted; two canals, into which the tears are received near the inner angle of the eye; the sac, into which these canals open; and the duct, through which the tears pass from the sac into the nose. The constant movements of the upper eyelid induce a continuous gentle current of tears over the surface, and these carry away any foreign particle that may have been deposited on the globe of the eye.

222. MECHANISM OF VISION.—The uses of the different structures of the eye are readily understood. Assuming a general knowledge of the ordinary laws of geometrical optics, let us trace the course of the rays of light proceeding from any luminous body through the different media on which they impinge. If a luminous object, as, for example, a lighted candle, be placed at the ordinary distance of distinct vision (about ten inches) from the front of the eye, some rays fall on the sclerotic, and being reflected, take no part in vision; the more central ones fall upon the cornea, and of these some also are reflected, giving to the surface of the eye its beautiful glistening appearance, while others pass through it, *are strongly converged by it*, and, entering the aqueous humour, are probably also slightly converged there. Those which fall on and pass through the outer or circumferential part of the cornea are stopped by the iris, and are either reflected or absorbed by it; while those which fall upon its more central part pass through the pupil. The rays now impinge upon the lens, which, by the convexity of its surface, and by its greater density towards the centre, increases the convergence of the rays passing through it.

They then traverse the vitreous humour, the principal use of which appears to be to afford support to the expanded retina, and are brought to a focus upon that tunic, forming there an exact, but inverted image of the object (fig. 130).

223. ACCOMMODATION OF THE EYE FOR DISTANCE.—It will be found that we cannot distinctly see a distant and a near object at the same moment. For example, if we look through a railing at a distant church spire, and fix our attention on the spire, we do not distinctly see the railing; and *vice versâ*. This was early observed; but, until recently, the mechanism by which the eye accommodates or focuses itself for different distances was unknown. Cramer was the first to point out that if we bring a candle-flame near the eye in a dark room, we may see three images—1st, an erect image reflected from the cornea; 2d, an erect image on the anterior surface of the lens; and 3d, an inverted and very faint image on the posterior surface of the lens. He also showed that when the eye looks quickly at a near object, after having been for some time directed to a distant one, the middle image moves forwards nearer to the

Fig. 127.—Reflected images in the eye: A, for distance; B, for near vision.

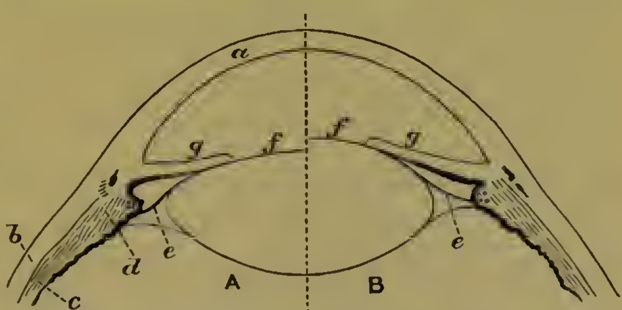


Fig. 128.—Action of Ciliary Muscles and Iris in accommodation:

A, (right or left) half; eye at rest, or focused for a distant object. B, (left or right) half; eye focused for a near object. *a*, cornea; *b*, sclerotic; *c*, anterior part of choroid; *d*, ciliary muscle; *e*, suspensory ligament of lens; *f*, anterior capsule of lens; *g*, iris.

first, and also becomes smaller, showing that for near vision the anterior surface of the lens becomes more convex (see fig. 127). Thus he showed conclusively that the accommodation of the eye for different distances is effected by changes in the curvature of the anterior surface of the lens. The physiological explanation is as follows :

The lens, which is elastic, is kept habitually in a state of tension by the pressure of the suspensory ligament (fig. 125, *g*), and consequently has a flatter form than it would take if left to itself. The ciliary muscle (fig. 125, *e*) contracts when we look at a *near* object. When contracting, by pulling on the ciliary processes (fig. 125, *f*), it relaxes the ligament, and thereby diminishes its elastic tension upon the lens. The anterior surface of the lens consequently becomes more convex, and thus the divergent rays from a near object are brought to a focus on the retina. The lens returns to its former shape when the ciliary muscle ceases to contract (see also fig. 128 and description). The power of thus accommodating the eye begins when we look at objects about 70 yards, and ends at a distance of about 10 inches from the eye.

Questions.

213 and 220. What are the refractive media through which light must pass before it reaches the retina?

214 to 218. Suppose you cut from the outside of the sclerotic to the centre of the eye, through what layers would the incision be made?

216. Describe the structure of the iris.

218, 219. Describe the layers of the retina.

220. Draw the form of the lens.

221. Describe the lachrymal apparatus.

222. Show how an image, say of an arrow, is formed on the retina.

223. Prove that the eye must be focused for objects at different distances. What is the mechanism of accommodation?

224. The Blind Spot.—Near the area of greatest sensibility to light we have a spot in the retina which is devoid of rods and cones, and hence is unaffected by images formed upon it. This is the *optic papilla* (fig. 125, *i*), or place of entrance of the optic nerve, and as its diameter is nearly $\frac{1}{12}$th of an inch, it subtends a visual angle of about 6 degrees. Lines

drawn from the border of the optic pore to the nodal point (the point where central rays cross in the lens), and produced outwards, will enclose a flattened cone whose base is contained within the visual field, and within which all objects will be invisible to the unmoving eye. This area is called the blind spot. Suppose, for example, the left eye being shut, the right eye be fixed upon the cross. When the book is held

X ●

at arm's length, both cross and round spot will be visible ; but if the book be approximated to about 8 inches from the eye, the gaze being kept steadily upon the cross, the round spot will at first disappear, but as the book is brought still nearer both cross and spot will again be seen. It may also be noted in this experiment, that there is no consciousness of a break of continuity in the visual field, no sensation, as we might imagine there would be, of darkness ; to put it shortly, there being no stimulation, there is not consciousness of a lack, but a lack of consciousness.

225. DEFECTS OF VISION.—It has been shown that the human eye is not a perfect optical instrument in the sense of being accurately corrected for *spherical* and *chromatic* aberration, but it is so nearly perfect in this respect that the defects escape our notice unless looked for with special appliances, and consequently we suffer no practical inconvenience. In some people there is a defect called *astigmatism*, in which the individual cannot see at the same distance, and in the same plane, a horizontal and vertical line with equal distinctness. It is usually due to differences in the curvatures of the vertical and horizontal meridians of the cornea. There are two common forms of defective vision, however, which require notice—namely, short-sightedness or *myopia*, and long-sightedness or *hypermetropia*. They are due to an abnormality either in the curvatures or in the density of the refracting media, or in the length of the horizontal axis of the eyeball. In *short-sightedness*, from too great a refractive power from either cause, the rays from objects at the ordinary range of distinct vision are brought too soon to a focus, so as to cross one another, and to diverge before they fall on the retina ; the

eye, in this case, being able to bring to the proper focus on the retina only those rays which were previously diverging at a large angle from a very near object (fig. 129, C). The correction for this deficiency is accomplished by interposing between the eye and indistinctly seen objects a *concave* lens, with a curvature sufficient to throw the images of external objects at the ordinary distance of distinct vision backwards upon the retina. In *long-sightedness*, on the other hand, there is an abnormal diminution of the refractive power, or the eyeball is too short from before backwards (fig. 129, B), so that the focus is behind the retina. This defect is corrected by a *convex* lens, which increases the convergence of the rays of light. The normal eye is seen in fig. 129, A: by it parallel rays, such as come from objects at a great distance, are focused on the retina.

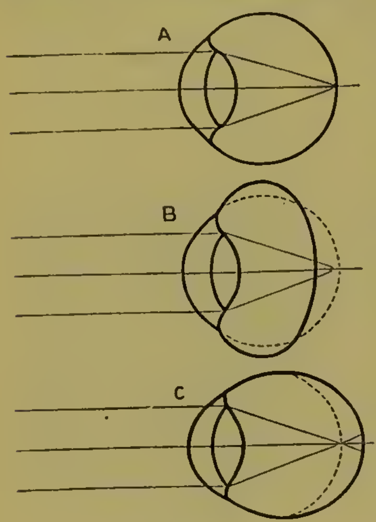


Fig. 129.

A, normal eye: parallel rays brought to a focus at retina. B, hypermetropic eye: globe shortened; parallel rays not yet brought to a focus when they reach retina. C, myopic eye: globe lengthened; parallel rays brought to a focus in front of retina. In *astigmatism* the vertical meridian of the cornea is usually the more convex.

226. Subjective Phenomena of Vision.—When small particles of matter occur in the aqueous or in the vitreous humour, they cast shadows on the retina which appear to float in the air before the eye, often like small black dots, but sometimes assuming grotesque forms. These are called *muscæ volitantes*. They are often seen during ill health, more especially if associated with bilious disorder. Another series of phenomena are produced by pressure on the eyeball, either continuous, or sudden as by a blow. Then a number of rings of various colours, or a flash of light, may be observed. These are termed *phosgenes*, and are due to mechanical irritation of the retina. Finally, if we fix the attention for a minute or two on a coloured surface, say a red wafer, brilliantly illuminated on a white ground, and then

transfer the gaze to another part of the room, or shut the eyes, in a second or two a huge wafer, of a colour complementary to the one at first looked on—that is, green—makes its appearance, and floats before us. Such phenomena are termed *after-images*, and are accounted for by supposing that the light from an illuminated surface fatigues a limited area of the retina, and that the after-image is due to the changes in the retina which attend its recovery from this fatigue. The three classes of phenomena just described are all examples of optical *illusions*, and must be distinguished from the *delusions* of the insane, which have their origin not in the sense organ, the eye, but in the brain.

227. POSITION OF OBJECTS ON THE RETINA.—In consequence of the bending of rays of light by the refractive media, the image of an external object is inverted on the retina, and yet we see objects erect. The probable explanation is, that the mind may perceive as correctly from an inverted as from an erect image. When we glance at a column from top to base, we move the eyeball downwards so as to bring successive parts on the yellow spot, and it is the feeling of movement which informs us which is top and which is base, not the inverted position on the retina, *of which we are unconscious*.

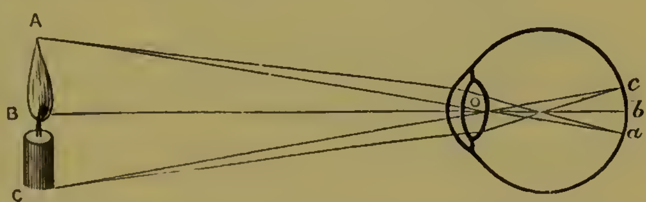


Fig. 130.—Diagram showing the visual angle, and also the path of rays through the eye.

The image of the point, A, is formed on the retina at *a*; of B at *b*; and of C at *c*. AOC is the visual angle. On the retina there is an inverted image, *cba*, of the object, ABC, and the size of this image depends on the size of the angle O.

228. SIZES OF OBJECTS.—The apparent size of any object depends on the size of the image formed on the retina, and this again on the size of the *visual angle*—that is, the angle formed in the lens by the pencils of rays

passing from the extreme limits of the object looked at (see fig. 130 and description).

229. SINGLE VISION WITH TWO EYES.—This phenomenon is explained by the fact that there are corresponding points on the retina, so that when, by an adaptive action of the muscles of the eyeball, an image is formed on a corresponding point in each eye, the mind is conscious of one image. If we alter the direction of the axis of one eye by pressing gently on that eye, an image is formed on a point of the retina of that eye which does not correspond to the point upon which the image falls in the other eye, and consequently we squint, or see two images.

QUESTIONS.

224. Define the position of the blind spot, and prove that it exists.
225. What is a short-sighted eye? How may the defect be remedied? Draw diagrams showing the state of the eye in emmetropia (normal), myopia, and hypermetropia.
226. Explain the cause of *muscæ volitantes*. What are phosgenes?
227, 228. Show geometrically how an image is formed on the retina.
229. What is meant by the term 'corresponding points?'

Hearing.

230. GENERAL DESCRIPTION OF EAR.—The organ of hearing is composed of three portions, the external, middle, and internal ear. The external ear consists of the *auricle*, which presents elevations and depressions, the functions of which are to receive and reflect the vibrations of the air which constitute sound, and to transmit these by a tube, partly cartilaginous, partly bony, called the *auditory canal* (fig. 131, 15, 16), to the middle ear. The middle ear is named the *tympanum* or drum, 21. It is a cavity in the petrous or hard portion of the temporal bone. It is shut off from the auditory canal by the *membrane of the drum*, 17, a thin structure capable of vibrating when acted on by the vibrations of the air. The tympanum communicates with the back of the throat by the *Eustachian tube*, 23, the function of which is to

equalise atmospheric pressure on both sides of the vibrating membrane. When this tube becomes stopped mechanically by enlargement of the tonsils, partial deafness is the result, and when cleared so as again to allow air to pass into the tympanum, hearing at once returns to

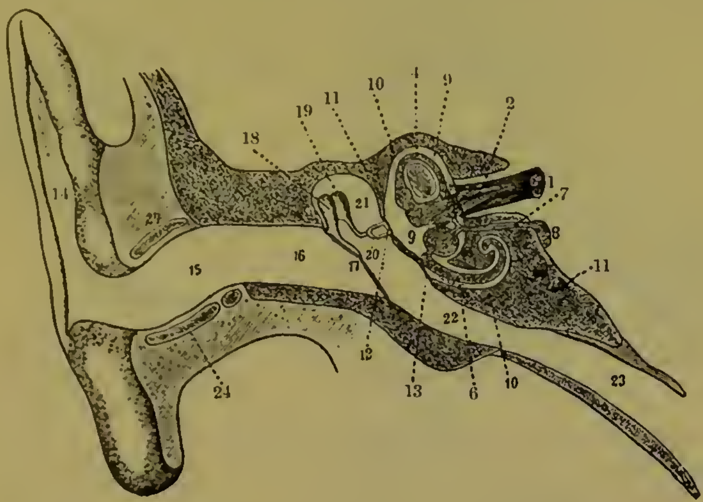


Fig. 131.—Diagram of the Ear ; natural size :

1, auditory nerve ; 2, internal auditory meatus closed by the cribriform plate of bone through the perforations of which the branches of the auditory nerve pass to the ear ; 3–8, membranous labyrinth composed of 3, utricle, 4, semicircular canals, 5, saccule, 6, duct of the cochlea (the coils not entirely shown), 7, endolymphatic duct with, 8, its saccule lying inside of the cranial cavity ; 9, lymphatic space surrounding the membranous labyrinth ; 10, osseous labyrinth of compact bone lying in the more spongy substance of the petrous bone, 11, 11 ; 12, the oval window, filled by the foot-plate of the stirrup-bone ; 13, the round window, across which is stretched the internal tympanic membrane ; 14, auricle ; 15, 16, external auditory meatus ; 15, its cartilaginous, and, 16, its bony part ; 17, tympanic membrane ; 10–20, auditory ossicles ; 18, hammer ; 19, anvil ; 20, stirrup ; 21, middle ear ; 22, osseous, and, 23, cartilaginous portion of the Eustachian tube ; 24, cartilages of external auditory meatus.

its normal state. Stretching across the tympanum we find a chain of small bones, one of which, the *malleus*, or hammer (figs. 131, 18, and 133, *m*), is attached by a long handle, *h*, to the drum ; this unites by a joint with another, the *incus*, or anvil (figs. 131, 19, 132, and 133, *sc*, *lc*) ; which in turn bears the *stapes*, or stirrup (figs. 131, 20, and

133, *s*); the base of this is fixed to a small oval membrane closing an aperture, the *fenestra ovalis*, which communicates with the internal ear (fig. 131, 12). The function of this chain of bones, which is really a

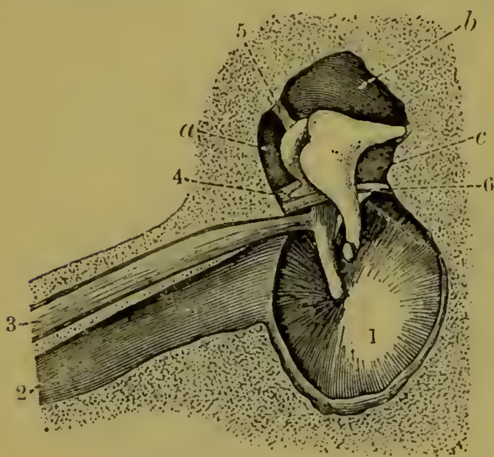


Fig. 132.—Incus and Malleus of the right side seen in their Natural Position in the Tympanum:

1, tympanic membrane; 2, Eustachian tube; 3, tensor tympani muscle seen attached to the malleus; 4, anterior ligament of the malleus attached to the processus gracilis; 5, superior ligament of the malleus; 6, chorda tympani nerve; *a*, *b*, *c*, sinuses or spaces connected with the tympanum in which the ossicles move freely.

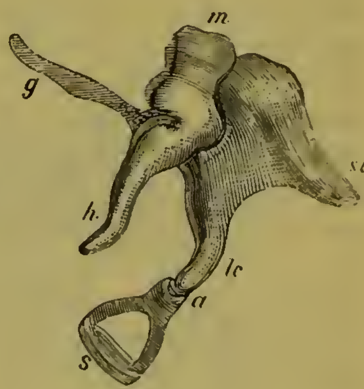


Fig. 133.—Ossicles of the Left Ear as seen from the outside and below:

m, head of the malleus; *g*, the slender process, or processus gracilis; *h*, the manubrium or handle; *sc*, the short crus, and *lc*, the long crus of the incus; *a*, the position of the lenticular process, through the medium of which it articulates with the head of the stapes; *s*, the base of the stapes.

jointed lever, is to convey vibrations or minute variations of pressure from the membrane to the internal ear.

231. Structure of Internal Ear.—The internal ear, or labyrinth, so called on account of its complexity of structure, is the essential part of the organ of hearing, because here we find the filaments of the auditory nerve which are ultimately to receive impulses originally produced by vibrations of the air, and conveyed by the intermediate structures already described. It is made up of three parts—the *vestibule*, or central part; the *semicircular canals*, three in number, which communicate by

five openings with the vestibule ; and the *cochlea*, so called from its resemblance to a snail shell (fig. 135). Each of these parts is excavated from the substance of the bone, and forms the bony or osseous labyrinth ; but within this we have a fibrous structure exactly corresponding in shape, the membranous labyrinth (fig. 134). The osseous is separated from the membranous labyrinth by a fluid called the *perilymph;* and within the membranous portion there is another fluid known as the *endolymph.* The terminations of the auditory nerve end in vibratile structures in the membranous portion ; and by the presence of the two fluids

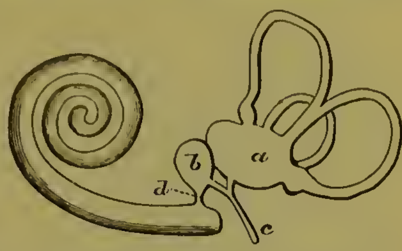


Fig. 134.—Scheme of Mammalian Labyrinth :

a, utricle ; *b*, saccule ; *c*, aquæductus vestibuli, dividing into two branches, going to saccule and utricle respectively ; *d*, canalis or ductus reuniens.

Fig. 135.—Interior of the Osseous Labyrinth :

V, vestibule : *av*, aqueduct of the vestibule ; *o*, fovea semi-elliptica ; *v*, fovea hemispherica. S, semicircular canals : *s*, superior ; *p*, posterior ; *i*, inferior ; *a*, *a*, *a*, the ampullar extremity of each. C, the cochlea : *sv*, osseous zone of the lamina spiralis, above which is the scala vestibuli, communicating with the vestibule ; *st*, scala tympani, below the spiral lamina.

just mentioned, the most delicate pressures of the air communicated directly to the membrane of the drum and chain

of bones, or indirectly through the bones of the head, are conveyed to these vibratile structures, and by these to the nerves.

232. STRUCTURE OF COCHLEA.—The structure of the cochlea is very remarkable. It consists of a central pillar, round which a tube makes two and a half coils. This tube is divided into two compartments by a partition, partly bony, partly membranous (fig. 135, C, *sv*). The upper portion communicates with the vestibule, and, from its fancied resemblance to a stair, has been called *scala vestibuli.* Suppose we ascended this stair to the apex of the cochlea, we would there find a

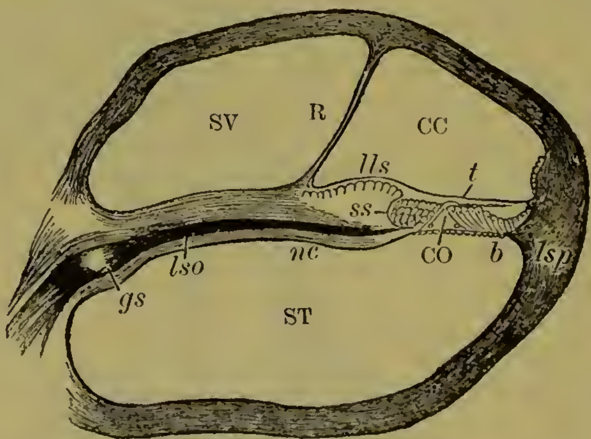


Fig. 136.

Section through one of the Coils of the Cochlea (diagrammatic):

SV, scala vestibuli; ST, scala tympani; CC, canal of the cochlea; *lso*, lamina spiralis ossea, or spiral plate of bone; *lls*, limbus of the spiral lamina; R, Reissner's membrane; *ss*, spiral sulcus or groove; *t*, tectorial membrane; CO, organ of Corti; *b*, basilar membrane; *lsp*, spiral ligament; *nc*, cochlear nerve; *gs*, spiral ganglion in course of cochlear nerve.

small opening communicating with the lower compartment, which has been called the *scala tympani.* It receives this name because at the bottom it communicates with the tympanum by a round opening, called the *fenestra rotunda*, closed by a thin membrane (fig. 131, 10, 13). The cochlear branch of the auditory nerve enters the base of the pillar just mentioned, and distributes branches to the membranous portion of the scalæ. But this is not all. Between the two scalæ or staircases,

in a triangular space, there is a remarkable organ called the *organ of Corti* (fig. 136, CO). This is a complicated structure, consisting essentially of three or four thousand

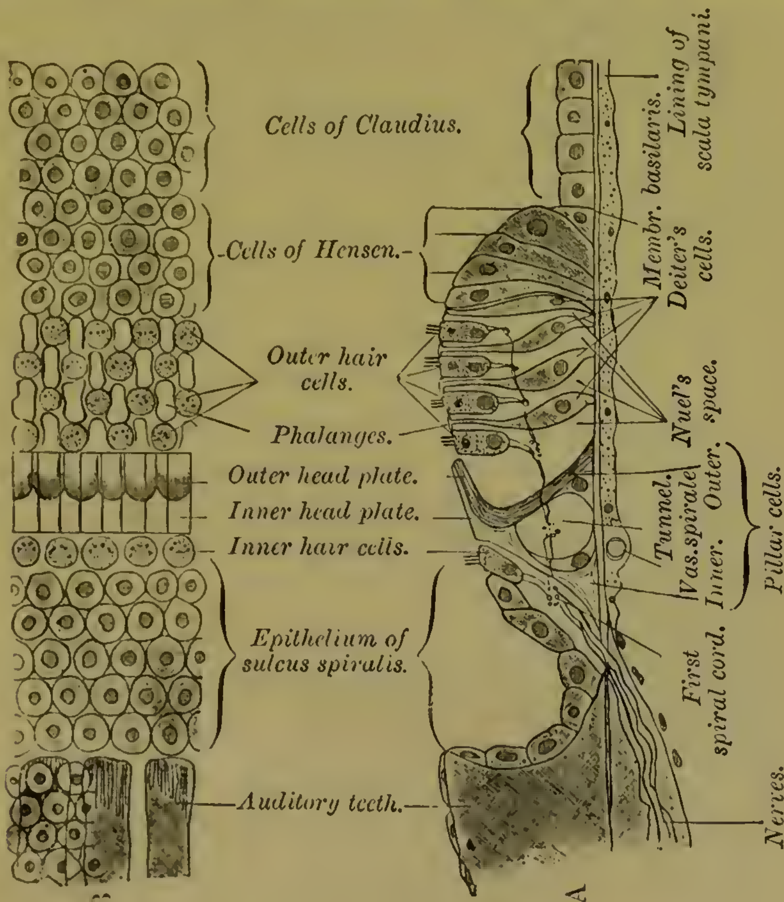


Fig. 137.—The Organ of Corti.

A, seen in transverse section ; B, seen from above ; very highly magnified. The two views are placed side by side, and the names between apply to the view on each side. Note, by a study of fig. 136, where the organ is situated (CO).

jointed rods, supporting ciliated cells called *hair-cells*, which are apparently capable of vibrating. These are connected with auditory nerve filaments (see figs. 131, 1, 136, *nc*, and 137, A, *nerves*.

233. Functions of Parts of Ear.—We know little

regarding the functions of the different parts of the internal ear. That they have different functions we infer from the structure being so dissimilar, and also from the facts of comparative anatomy. In the animal kingdom, the vestibule first appears; to this are superadded the semicircular canals; and, lastly, the cochlea, which increases in complexity from the lower orders of the mammalia up to man, in whom it is one of the most complicated organs of the body. The vestibule probably enables us to experience a sensation of sound as such; the semicircular canals may assist in determining the direction of sounds, or, according to recent researches, may so affect us as to give us the *sense of equilibrium* or of *rotation*; while there are many arguments in favour of the view that the cochlea, as we find it in man, with a highly elaborated organ of Corti, may be the mechanism by which we appreciate the *pitch* and *quality* of musical sounds, which act so powerfully in exciting the emotions.

234. RANGE OF HEARING.—The range of hearing, like that of vision, varies in different persons. Some are insensible to sounds that others hear. Many cannot hear the chirp of a grasshopper or the squeak of a bat, two of the shrillest sounds produced by living beings. The range of the ear is much greater than that of the eye in detecting movements which produce vibrations. Thus we hear the sound produced by a vibrating rod or string long after we have ceased to see the movements. The range of the human ear is about eleven octaves. The lowest sound recognisable as musical is produced by about 32, and the highest by about 32,000 vibrations per second.

QUESTIONS.

230. Where is the drumhead of the ear situated? What is the tympanum? How does the tympanum communicate with the external air? Describe the chain of bones.

231. What are the parts of the labyrinth? How are pressures communicated from the drumhead to the labyrinth?

232. What is the cochlea? Draw a diagram showing a section through the tube of the cochlea. Where is the organ of Corti?
233. What uses have been assigned to the semicircular canals?
234. What is a vibration? What is the range of the ear as regards the appreciation of vibrations?

The Muscular Sense.

235. There is still another sense, called the muscular sense, or sense of weight. If we close our eyes, and hold a weight on the palm of the outstretched hand, we experience a peculiar sensation. It is not referable to any of the five senses, except, perhaps, to touch. But it is not simple touch. We are conscious of an effort to sustain the weight, and of a firm condition of the muscles of the arm. This sensation is the muscular sense. It is the sensation we experience when any groups of the voluntary muscles are called into action, and by it we become aware of the condition of these muscles. By means of this sense, we stand erect, we walk, balance ourselves on a narrow ledge, throw stones or weapons, play on many instruments, &c.; and it adds largely to our feelings of pleasure. It is chiefly by means of the muscular sense that we receive our notions of solidity, relief, and of things being external to, and at a certain distance from, ourselves (fig. 156).

Question.

235. Prove the existence of a muscular sense.

CHAPTER XIV.

THE NERVOUS SYSTEM.

236. General Description of Nervous System.—The vital processes already described (with the exception of those connected with the senses) belong to the class

of functions known as *vegetative*, because certain of them are common to vegetables as well as to animals. These functions have as their object the preservation of the plant. The animal has, however, another set of organs, by the use of which it becomes conscious of a world external to itself, and by which, as stated above, a control, both stimulating and regulative, is exercised over the other organs. By means of certain functions, which, from their occurrence in animals only, are termed *animal*, all the higher animals, and especially man, are endowed with sensation, motion, and volition. These powers are due to the presence of a nervous system, including two sets of nerves and nerve-centres—namely, the *cerebro-spinal system* and the *sympathetic system* (see p. 38).

The former consists of the *cerebro-spinal axis*, composed of the brain and spinal cord, and the *cerebral* and *spinal nerves* connected with this axis; while the latter consists chiefly of a double chain of *ganglia* or nervous masses, lying at the sides of the spinal column, and united with one another and with the spinal nerves by connecting threads of nervous substance (fig. 154).

237. Characters of Nervous Matter to the Naked Eye.—Nerve matter is of two kinds, *white* and *gray*, which may be readily seen by cutting through the brain of a sheep or of any other animal, when it will be observed that there is an outer layer of gray matter, while the interior is white. In the spinal cord these relations are reversed, the gray matter lying in the centre.

238. Structure of Nerves. — These consist of a number of delicate fibres, each of which is transparent as glass when examined in a perfectly fresh state, but usually seen with two well-defined lines on each side of a broad clear space. The central part is called the *axis-cylinder*, and the outer part, the *white substance of Schwann*. Very minute nerve-fibres, such as those obtained near the surface

of the brain (fig. 138, *e*, *f*), show no white substance. The nerve-fibres vary much in diameter. Those of the *sympathetic* have no white substance. At certain distances the white substance is interrupted, while the axis-cylinder is continuous, constituting the so-called *nodes* of *Ranvier*. During life the substance in the interior of the sheath of

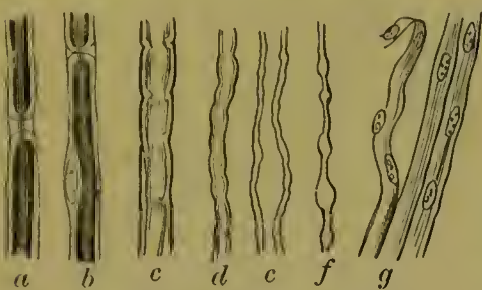


Fig. 138.—Nerve-fibres.

c, ordinary sized nerve-fibre showing axis-cylinder surrounded by white substance; *d*, smaller nerve-fibre, with white substance scarcely visible; *e*, still smaller, with no white substance visible; *f*, varicose nerve fibre, from gray matter near surface of brain; *a*, nerve-fibre, coloured and acted on by *osmic* acid, showing one of the *nodes of Ranvier*, or complete interruption of the white substance with continuity of the axis-cylinder; *b*, nerve-fibre showing nucleus and node of Ranvier (the axis-cylinder is blackened); *g*, non-medullated nerve-fibre from sympathetic, having no white substance, and nucleated at intervals.

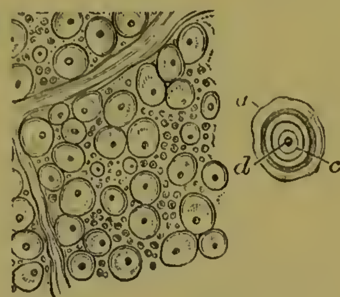


Fig. 139.

Transverse Section of Nerve:

To the left is seen a portion of a section of a nerve. Observe the partitions of connective tissue that separate groups of nerve-fibres from each other. The nerve-fibres seen cut transversely vary in diameter. A section of a single fibre is seen to the right: *a*, neurilemma, or Schwann's sheath; *c*, axis-cylinder; *d*, white substance.

the nerve-fibre (the *neurilemma*) is in a semifluid state, and the conception of a nerve-fibre to be formed is, a thin cylinder (*neurilemma*) enclosing a cylinder of semifluid substance (*white substance of Schwann*), within which there is a *core* of semifluid matter, of different consistence from the last, called the *axis-cylinder* (fig. 139).

239. NERVE-CELLS.—When nerve-fibres are traced into the nerve-centres, they are found to terminate in *nerve-cells*, which are of various forms. These cells are composed of

protoplasmic matter, slightly molecular, and usually having issuing from them one or more *poles* or processes. One

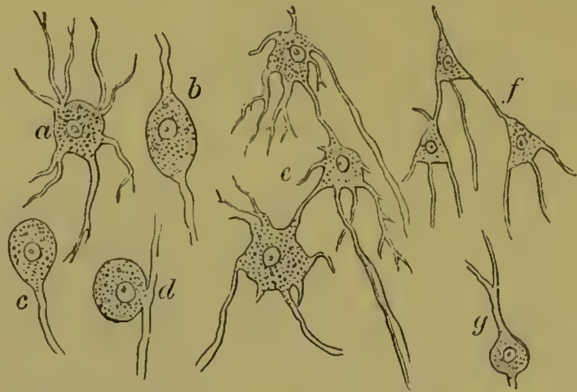


Fig. 140.—Various forms of Nerve-cells.

a, *multipolar*, from gray matter of spinal cord; *b*, *d*, *bipolar*, from ganglia on posterior roots of spinal nerves; *c*, *g*, *unipolar*, from cerebellum; *g*, shows indications of a process coming off at lower end; *e*, union of three multipolar cells in spinal cord; *f*, union of three *tripolar* cells in gray matter of cerebral hemispheres. Nerve-cells are probably never connected, as shown in *e* and *f*. All the processes, with the exception of the one giving origin to an axis-cylinder, break up into extremely fine fibres, or, as now called, an *arborisation*, like the twigs of a tree (fig. 141, *a.p.*).

large process issuing from a cell is in continuation with the axis-cylinder of a nerve-fibre (fig. 141, *a.p.*). They vary in size from the $\frac{1}{5000}$th to the $\frac{1}{400}$th of an inch. The function of these cells is to receive or transmit nervous impulses, but how they do so is quite unknown. Gray matter is composed chiefly of these cells lying amongst extremely delicate connective tissue termed *neuroglia*.

Fig. 141.
Nerve-cell from Spinal Cord: *a.p.*, axis-cylinder process.

240. Functions of a Nerve-fibre. — The function of the nerve-fibre is to receive an impression of any kind—mechanical, chemical, thermal, electrical, or volitional—

thereupon to generate an influence, and to conduct this influence to or from a nerve-centre. The rapidity of the nerve-impulse is, in cold-blooded animals, from 75 to 120 feet per second; incomparably slower than light or electricity. In warm-blooded animals, such as man, it travels at a rate of about 200 feet per second.

QUESTIONS.

236. Compare the central nervous system with the sympathetic system.
237. When you cut into the brain or spinal cord, what kinds of matter may be seen?
238. Describe the structure of a medullated nerve-fibre.
239. Draw a diagram showing the various kinds of nerve-cells.
240. What are the chief functions of a nerve-fibre? What is the rate at which an impulse is transmitted along a nerve?

THE DEVELOPMENT OF THE NERVOUS SYSTEM IN THE ANIMAL KINGDOM.

241. Nothing conduces sooner to an intelligent comprehension of the complicated nervous system of man and of the higher animals than the study of the gradual development of the nervous system throughout the animal kingdom, from its simpler to its more complex forms. Suppose the surface of an animal's body to be covered with epithelium cells, as in fig. 142, *c*, one of these is by-and-by set aside for the reception of a special stimulus, such as pressure, or light, or sound. A process (the beginning of a nerve) passes from this cell to another cell situated deep in the tissues of the animal, but without actual continuity at *a*, and this cell (the beginning of a central nervous system) acts on the muscular fibre *b*, causing contraction or movement. A stimulus applied to *d* caused movement of *b*.

A still more complicated arrangement is seen in fig. 143. Here a nerve-cell *f* in the brain acts through the fibre *e* on the cell *c*, situated, say, in the spinal cord (but not continuous with it), and *c*, in its turn, acts on the muscle-fibre *a*, by the nerve-fibre *b*. From *c*, fibres *d* and *d* pass off, so that a

stimulus starting at *f* may initiate movements in many muscle-fibres by such offsets as *d* and *d*.

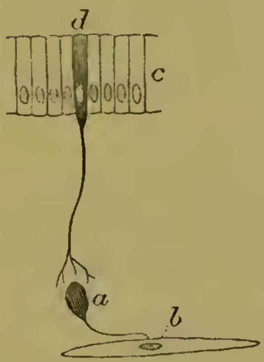


Fig. 142.—Simple plan of nervous mechanism as in lower forms of life.

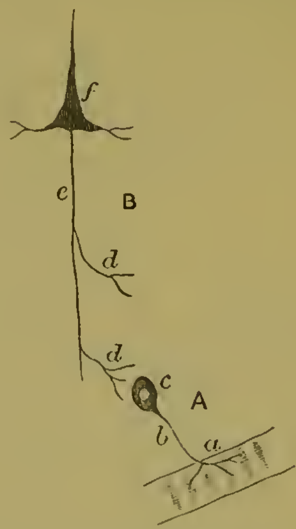


Fig. 143. — Complicated plan of nervous mechanism, causing movement, as in higher animals.

242. Nervous System of Invertebrates.—In none of the *Protozoa*, including such animals as sponges, infusoria, &c.,

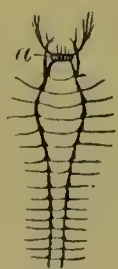


Fig. 144. — Nervous System of a *Serpula* or Seaworm :
a, cephalic ganglion.

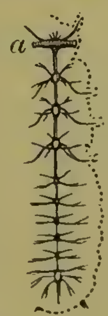


Fig. 145. — Nervous System of an Ant :
a, cephalic ganglion.

Fig. 146. — Nervous System of a Crab :
a, cephalic ganglion; *b*, mass of ventral ganglia fused together.

has any trace of a nervous system been discovered. Neither is any rudiment of it to be found in the *Hydrozoa*, the first subdivision of the cœlenterate group of animals ; but in the

Actinozoa, which comprehends such animals as the sea-anemone, it is first discovered as a little knot or nodule of nervous matter, from which delicate fibres radiate. Such a nodule is called a *ganglion*, and the filaments constitute *nerves*. Among the *Echinodermata*, such as starfishes, sea-urchins, &c., we find the nervous system consisting of a number of ganglia, connected together, so as to form a ring, or *nervous circle*, from which nerve-filaments pass to various parts of the body. In some of the *Annelidæ*, or worms, we find (fig. 144) a ganglion, *a*, in the neighbourhood of the head, from which two nervous cords pass along the ventral (or belly) surface of the animal. In the *Mollusca*, or shellfish, there are usually at least three ganglia with radiating nerves—one in the head, one in the foot, and one posterior and above the alimentary canal. In the *Insecta*, or insects (fig. 145), we find a large ganglion in the head, *a*, from which a double cord passes backward along the *ventral* surface of the animal, and in connection with which there are three or more ganglia, as seen in the figure. In the *Crustacea*, such as the common crab (fig. 146), there is a large ganglion near the anterior extremity, with nerves for the eyes and antennæ, *a*, while behind we find the ventral chain of ganglia fused into one mass, *b*.

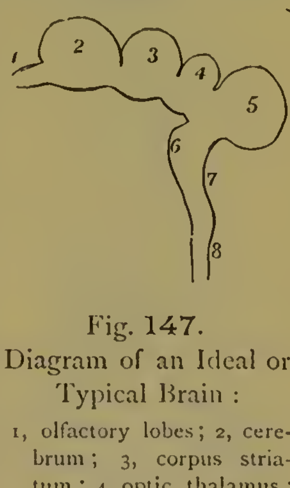


Fig. 147.
Diagram of an Ideal or Typical Brain:
1, olfactory lobes; 2, cerebrum; 3, corpus striatum; 4, optic thalamus; 5, cerebellum; 6, pons Varolii; 7, medulla oblongata; 8, spinal cord.

243. Nervous System of Vertebrates.—All of the groups now mentioned belong to the invertebrate subdivision of the animal kingdom, and all have their nervous system along the *ventral* aspect of the body. We now come to the vertebrate subdivision, or those having a backbone, and here we meet with another nervous system extending along the *dorsal* aspect of the animal, to which anatomists have given the name of the *cerebro-spinal system*. This consists of a chain of ganglia constituting the *brain*, behind which there is an elongated mass of nervous matter, running from the brain through the canal of the vertebral column, called the *spinal*

cord, or *spinal marrow*. In all vertebrate animals, the spinal marrow seems to be much alike in general structure and arrangements (although the spinal cord of a man is a more complicated organ than that of a rabbit), but one animal differs from another (as a fish from a frog, or a pigeon from a rabbit) mainly in the degree of development of the brain. The brain consists of a series of ganglia which, in a typical or ideal brain, might be thus represented (fig. 147). These ganglia, from before backwards, are: 1, olfactory lobes; 2, cerebral lobes; 3, corpora striata; 4, optic thalami; 5, cerebellum; 6, pons Varolii; 7, medulla oblongata; and 8, spinal cord. Between 4 and 5 we also find a mass of nervous matter termed the optic lobe or lobes.

Such a brain is seen, for example, in many *fishes* (fig. 148),

Fig. 148.
Brain of Common Gurnard:

1, olfactory; 2, cerebral lobes; 3, corpora striata; 4, cerebellum.

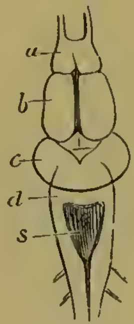


Fig. 149.
Brain of Common Frog:

a, olfactory; *b*, cerebral lobes covering corpora striata; *c*, corpora quadrigemina, or optic lobes; *d*, cerebellum (rudimentary); *s*, back of medulla showing fossa.

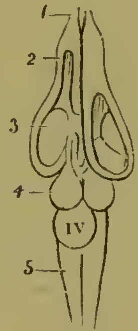


Fig. 150.
Brain of Tortoise:

1, olfactory: 2, cerebral lobes; 3, corpora striata; 4, optic lobes: IV, cerebellum; 5, medulla. Part of the surface of the cerebral lobes has been removed to show the cavities in the interior termed the *ventricles*.

where the cerebral hemispheres, 2, are still of very small size, and do not overlap any of the adjacent structures. The same arrangement may also be studied in the brain

of *amphibians*, such as the common frog (fig. 149); but here we find the cerebral lobes larger, so that they now extend backwards so as to cover the *corpora striata*. When we ascend to *reptiles*, such as the tortoise (fig. 150), we find the cerebral hemispheres larger, broader, and thicker as regards the amount of gray nervous matter on the surface. The cerebellum is still feebly developed. In the brain of birds the cerebral lobes are still further developed (fig. 151), and the cerebellum has become so large as to wedge in between the two optic lobes and push these towards the base of the brain. The mammalian brain shows the hemispheres of the cerebrum still larger, so that they now project so far posteriorly as to

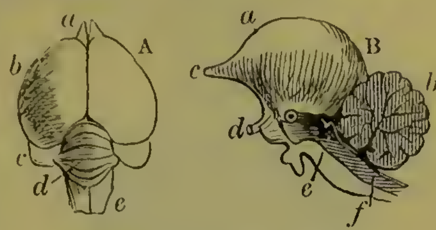


Fig. 151.—Brain of Pigeon: A, view from above. B, lateral view of a bisected brain. A: *a*, olfactory; *b*, cerebral lobes; *c*, optic lobes; *d*, cerebellum; *e*, medulla. B: *a*, cerebrum; *b*, cerebellum; *c*, olfactory; *d*, optic nerves; *e*, medulla; *f*, cord.

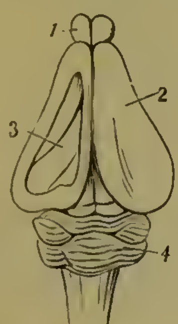


Fig. 152.—Brain of Rabbit: 1, olfactory; 2, surface of cerebral hemisphere; 3, cavity in brain called a *ventricle*, in the floor of which is seen the *corpus striatum*; 4, cerebellum.

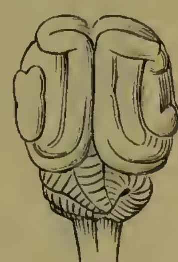


Fig. 153.—Brain of Common Cat, showing Convoluted Surface.

cover not only the corpora striata and optic thalami, but also the optic lobes. The cerebellum is also much more highly developed. The brains of the lower mammals, such as the rabbit (fig. 152), are nearly smooth on the surface, and exhibit only a trace of those elevations and depressions

which we meet with on the surface of the brains of such an animal as the common cat (fig. 153), where we find the surface distinctly convoluted. The *convolutions* increase in number, depth, and complexity as the intelligence of the animal increases, until we come to the brain of man, where in a well-developed brain we find them presenting the appearance depicted in (figs. 155 and 156). It will thus be seen that as we ascend from the lower to the higher vertebrates, the brain becomes more and more complex in structure, chiefly by the great growth and development backwards, of the cerebral hemispheres, and by the appearance of convolutions on the surface of these, indicating increase of gray matter. The general plan of the nervous system in man is shown in fig. 154.

Fig. 154.

a, cerebrum ; *b*, cerebellum ; *c*, medulla oblongata ; *d*, spinal cord, from which the spinal nerves arise ; *e*, brachial plexus ; *f*, sciatic nerve.

Questions.

241. Describe the simplest form of nervous system.
242. Show how the nervous system gradually becomes complicated in invertebrate animals.

243. Draw a diagram showing the parts in the typical brain of a vertebrate animal. Compare the brains of a fish, a frog, and a tortoise. Describe the brain of a bird. Compare the brains of a rabbit and a cat. How do the brains of the lower mammalia differ in general from the brain of a man?

THE HUMAN BRAIN.

244. General Description.—The brain consists of the

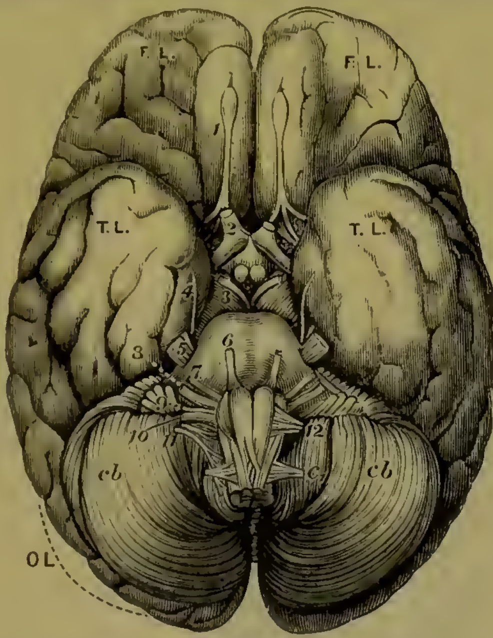


Fig. 155.—Under Surface, or Base of Brain:

F.L., T.L., O.L., frontal, temporal, and occipital lobes of the cerebrum; *cb*, *cb*, cerebellum, the medulla oblongata lying between its two lobes. *Cranial Nerves.*—1. olfactory lobe (the nerve of smell); 2, optic nerve (nerve of sight); 3, third or oculo-motor nerve, motor nerve to most of the muscles of the eye; 4, fourth or trochlear nerve, motor nerve to the superior oblique muscle of the eye; 5, fifth, trigeminus, or trifacial, sensory and motor, the large root sensory to the face and eyes, &c.; the small root, motor to muscles of mastication; 6, sixth or abducens nerve, to external rectus muscle of eye, turns eyeball outwards; 7, seventh or facial, motor to muscles of expression; 8, eighth or auditory nerve, sensory for hearing (cochlea) and for equilibration (semicircular canals); 9, glosso-pharyngeal, sensory nerve of taste, and motor to some of the muscles of deglutition; 10, pneumogastric, sensory and motor to larynx, lung, heart, and stomach; 11, spinal accessory, motor to muscles of heart (inhibitory) and sterno-mastoid and trapezius; 12, hypoglossal, motor to all the muscles of the tongue; c_1, first cervical spinal nerve.

cerebrum, or brain proper, which occupies the whole of the

upper and front parts of the cavity of the skull; the *cerebellum*, or little brain, lying beneath the hinder part of the cerebrum; and the *medulla oblongata*, or oblong marrow, which may be regarded as a continuation of the spinal cord within the cavity of the cranium, and as forming the connection between the brain and cord. The cerebrum and cerebellum are almost completely divided into two lateral halves by a deep median longitudinal fissure; and the surface of the former is indented by a considerable number of tortuous furrows, nearly an inch deep, into *convolutions*. As the gray matter is extended into these furrows, its quantity is thus vastly increased (see figs. 155, 156, and 157).

Fig. 156.

Cerebrum—upper surface (Quain):

To show, firstly, division into two nearly equal hemispheres by the great median fissure; secondly, general appearance and apparent irregularity of arrangement of the convolutions and fissures; F.L., frontal lobe; O.L., occipital lobe.

At the base of the cerebrum, and connected with it, are two large ganglionic masses of gray and white matter, called the *corpora striata;* behind these, other two bodies of a similar nature, the *optic thalami;* and still farther back, four bodies, two on each side, the *corpora quadrigemina*. All these parts of the brain are connected with each other by numerous nerve-fibres. The fibres from the spinal cord pass upwards in the medulla

oblongata; those from the posterior parts of the cord going chiefly to the cerebellum, while those from the anterior parts pass chiefly to the cerebrum. In the cerebrum, cerebellum, and ganglia we also find fibres running from their anterior to their posterior ends, while other fibres run transversely, and unite corresponding parts on opposite sides of the brain (fig. 157, *corpus callosum*). Thus there is evidently community of function.

245. FUNCTIONS OF DIFFERENT PARTS OF THE BRAIN. —The functions of these different parts may be briefly stated to be as follows: (1) the *cerebrum* is the seat of sensation, volition, emotion, of those intellectual powers,

Fig. 157.—Vertical Section of Brain.

a, *a*, cerebrum and convolutions; *b*, optic thalamus; *c*, corpora quadrigemina; *d*, section of cerebellum; *e*, optic nerve; *f*, pons Varolii; *g*, medulla oblongata.

in short, which constitute MIND; (2) the *cerebellum* is the chief regulator of muscular movements; (3) the *corpora striata* are great centres of voluntary movement, not of volition, but of the nervous mechanism by which, when we will by means of the cerebrum, the influences are sent along the spinal cord to the various muscles; (4) the *optic thalami* collect and transmit tactile (touch) impressions coming

from all parts of the body which excite sensation; (5) the *corpora quadrigemina* receive impressions by the optic nerves from the eyes, and transmit these to the cerebrum, where there is then the consciousness of sight; and (6) the *medulla oblongata*, and an adjoining part called the *pons Varolii*, are the seat of the nervous influences which regulate swallowing, breathing, and other important involuntary movements. The parts of the brain last mentioned (6) are absolutely essential to life. The other parts may be cut or mutilated without instant death, but this quickly follows injury to the medulla.

246. MOTOR AREAS.—Observations made on the cerebral hemispheres by stimulating small areas on their surface by feeble electric currents, have led to the discovery of certain 'centres' in the convolutions which, when stimulated, cause movements of definite groups of muscles. These centres have been termed *motor*-centres. There is thus a centre in the cortex of the brain for each muscle and group of muscles. Each centre probably receives sensory impulses from skin or mucous membrane, or from other centres in the brain itself, which impulses in turn stimulate the centre so as to cause movements of specific groups of muscles.

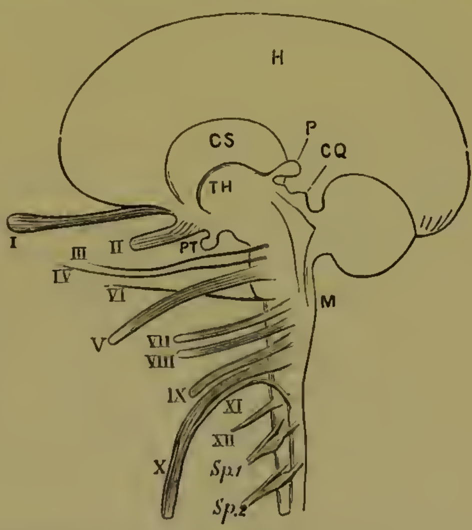
247. FUNCTIONS OF NERVES.—Nerves have different functions. When an influence travels along a nerve to a muscle, it excites the muscle to contract, and the former is then called a *motor* nerve; when it travels to the brain and causes a sensation, we call such a nerve *sensory*. A third class of nerves, when stimulated, convey impressions to glands, and the consequence is *secretion*. There is no evidence that there is any difference of structure between motor and sensory nerves. The difference of *result* on stimulating a nerve depends on its mode of termination. For example, if it terminate in the hemispheres of the brain, sensation or pain is felt; if in a muscle, the result is contraction; if in a gland, the secretion is augmented or diminished; if in a blood-vessel, the vessel may contract or dilate. Most

nerves contain both sensory and motor fibres. Some are purely sensory, as certain parts of the fifth cranial nerve; others purely motor, as the facial, or seventh cranial nerve; while all the spinal nerves have both sensory and motor fibres. Certain nerves respond only to particular stimuli. For example, the optic nerve is affected only by vibrations of rays of light, acting in the first instance on a special terminal apparatus called the *retina*. Such are called *special sensory* nerves, and include those of sight, hearing, taste, smell. The nerves of touch are those of common sensibility distributed to the skin (see also pages 73 to 76).

248. Cranial and Spinal Nerves.—Twelve pairs of

Fig. 158.—Diagram of the Brain, showing origin of the cranial nerves:

H, hemispheres; CS, corpora striata; P, pineal gland; CQ, corpora quadrigemina; TH, optic thalami; PT, pituitary body; M, medulla. The Roman numerals indicate the nerves. *Sp.* 1, *Sp.* 2, first and second spinal nerves. Observe the ganglia on the posterior roots.



nerves are given off from the brain, and thirty-one from the spinal cord. The spinal nerves are all *sensori-motor*—that is, they contain both kinds of filaments. The cranial nerves may be thus classified, and their general origin may be studied in figs. 155 and 158:

Order.	Anatomical Name.	Physiological Name.	Function.
1st Pair...	Olfactory, I.......	Olfactory......	Special sense, smell.
2d Pair...	Optic, II...........	Optic..........	Special sense, sight.
3d Pair...	Motor-oculi, III..	Motor-oculi..	Motor, for all the muscles of the eyeball except *two*, IV. and VI.

Order.	Anatomical Name.	Physiological Name.	Function.
4th Pair...	Trochlear, IV.....	Pathetic.......	Motor for superior oblique muscle of eyeball.
5th Pair...	Trigeminal, or Trifacial, V.	5th Nerve....	Sensori-motor—*sensory* to face, mouth, and part of tongue; *motor* to muscles of mastication.
6th Pair...	Abducens, VI....	6th Nerve....	Motor to external rectus muscle of eyeball.
7th Pair	Portio dura........	Facial	Two portions—*facial*, the motor nerve of the face; and the *auditory* — special sense of hearing.
	Portio mollis...... VII., VIII.	Auditory...	
8th Pair...	8th.................	8th............	Three distinct nerves: (1) The *glosso-pharyngeal*, IX., special sense of taste; (2) the *spinal accessory*, XI., motor to trapezius muscle in back, sterno-cleido-mastoid muscle in neck, and motor filaments to pneumogastric; (3) the *pneumogastric or vagus*, X., which extends through the cavity of the chest to the upper part of the abdomen—sensory and motor to pharynx, œsophagus, larynx, lungs, heart, and stomach; inhibitory to heart; *depressor* to vaso-motor centre in the medulla.
9th Pair...	Hypoglossal.......	Hypoglossal, XII.	Motor to muscles of tongue.

Questions.

244. Describe what is seen on the *under* surface of a human brain. What is the appearance of the *upper* surface of a human brain?
245. Suppose a human brain is divided into two parts by cutting through the great median fissure: what may be seen? Where are the following parts: cerebrum, cerebellum, corpus striatum, thalamus opticus, corpora quadrigemina, pons, and medulla?
246. What is meant by the term 'motor area' of the cortex?
247. What are the various kinds of nerves in the body, considered physiologically?
248. Draw a diagram showing the relative positions, from before backwards, of the cranial nerves. What are the nerves of the eyes, ears, tongue, nose? What is the motor nerve of the face? What is the nerve of the face affected in neuralgia? What nerve supplies the lungs, heart, and stomach?

THE SPINAL CORD.

249. The *spinal cord* or *marrow* is a cylindrical column of soft nervous tissue, extending from the base of the skull, where it is continuous with the *medulla oblongata*, to the region of the loins, where it tapers off to a thread in the lowest part of the vertebral canal (figs. 159 and 162). Its average length is eighteen inches. It is not only divided by two fissures in the middle, but each half is again divided longitudinally into three equal parts by two parallel series of nervous filaments, which are the anterior and posterior roots of the spinal nerves (figs. 160 and 161). The posterior root presents a swelling or ganglion, immediately beyond which the two coalesce into the trunk of a nerve which, after emerging through a hole called the intervertebral foramen, is distributed into branches to the parts it is destined to supply with nervous filaments; as, for example, the muscles of the trunk and limbs and the surface of the body (fig. 154). These roots have separate functions, the anterior being composed of motor, while the posterior contain sensory fibres. Hence if the anterior root be divided, or if the column of the cord

Fig. 159.—Diagrammatic View of Brain and Spinal Cord : *a*, cerebrum ; *b*, medulla oblongata ; *c*, cerebellum ; *d*, spinal cord ; *e*, spinal column ; *f*, cut ends of spinal nerves.

from which it springs be diseased, loss of *motion* in the part which it supplies is the result, while if the posterior root were similarly acted on, there would be loss of *sensibility*. The anterior columns of the medulla decussate (that is, send nerve-fibres across to the adjoining column); while the fibres of the posterior columns decussate higher up, near the upper part of the medulla oblongata. Consequently all the motor impulses starting, say, in the *right* hemisphere of the cerebrum excite muscular movements on the *left* side of the body and *vice versâ*, because all motor impulses cross over, chiefly in the medulla, and partly in the cord itself. Again, all sensory impulses from the *left* side of the body find their way to the *right* side of the brain, and *vice versâ*, because all sensory impulses cross over, chiefly in the medulla. A clot of blood therefore in the *right* hemisphere of the brain will cause paralysis both of motion and sensation on the *left* side of the body, while a similar injury to the *left* hemisphere

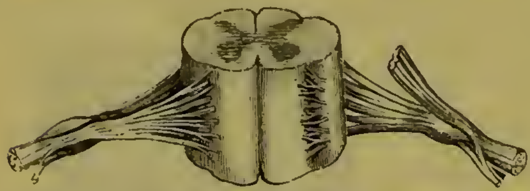


Fig. 160.—Diagram of a segment of the spinal cord, with a spinal nerve on each side.

Observe the crescent-formed gray matter in the cord surrounded by the columns of white matter. On the right side the *anterior* (motor) root has been cut. Observe the ganglion or swelling on the *posterior* (sensory) root.

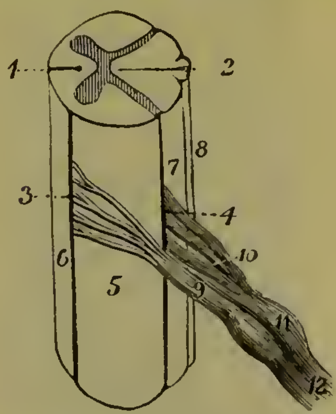


Fig. 161.—Side View of the Spinal Cord, showing the Fissures and Columns:

1, anterior median fissure; 2, posterior median fissure; 3, anterior lateral fissure; 4, posterior lateral fissure; 5, lateral column; 6, anterior column; 7, posterior column; 8, posterior median column; 9, anterior root; 10, posterior root; and 11, ganglion of (12) a spinal nerve.

will cause paralysis both of motion and sensation on the *right* side.

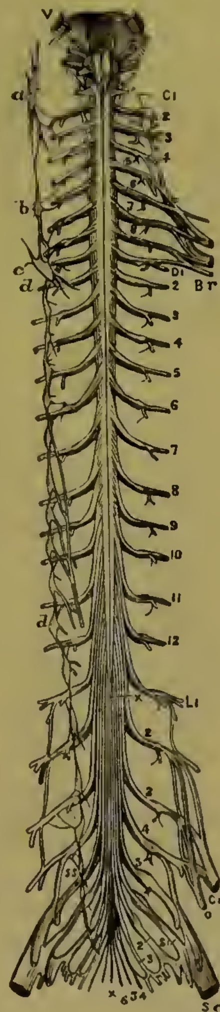


Fig. 162.—Diagram showing the close relation between the cerebro-spinal and sympathetic systems.

Parts of the brain and medulla are seen at the upper end, and the spinal cord is traced downwards. Observe the spinal nerves issuing from the sides of the cord and forming plexuses or networks, from which issue the great nerves going to the limbs, as at 6, 7, 8, 9, 10 above, and at the lower end, 1, 2, 3, 4. The cord of the sympathetic is seen on the left side. Observe the ganglia *a*, *b*, *c*, *d*, and the connections of these ganglia with the anterior roots of the spinal nerves. All the fibres of the sympathetic system originally come from the cerebro-spinal system.

The spinal cord is not only a great conductor of motor and sensory impulses: it also contains numerous centres for reflex action.

Questions.

249. How is the spinal cord connected with the brain? Describe the general arrangement of the spinal cord. What are the functions of the roots of the spinal nerves? Describe and explain the effects of a severe injury of the right hemisphere of the brain.

SYMPATHETIC SYSTEM OF NERVES.

250. This nervous system consists of a ganglionated cord found on each side of the spinal column, and giving to and receiving numerous filaments from the cerebro-spinal system (fig. 162 and description). Observation and experiment have shown that it has the following functions: (1) it controls the contractions of all structures which contain involuntary muscular fibre, such as the viscera; (2) it governs the various secretions, probably by acting on the blood-vessels of the glands; and (3) it is *vaso-motor*, controlling the calibre of the blood-vessels, and thereby regulating the circulation in the capillaries, the blood pressure in the greater arteries, and the distribution of animal heat. The general relations of the sympathetic system are seen in fig. 163.

QUESTIONS.

250. Where is the sympathetic system of nerves situated? How is the sympathetic system connected with the cerebro-spinal system? What are the general functions of the sympathetic system?

CHAPTER XV.

VOICE AND SPEECH.

251. There is a difference between *voice* and *speech*. Voice is a sound produced by vibrations of two thin folds of membrane called the vocal cords, placed in the larynx, at the top of the trachea or windpipe; *speech* is the modification of voice into sounds connected with certain ideas produced by the action of the brain, which we wish to communicate to our fellow-men. Many animals have voice; none, except man, have articulate speech expressive of

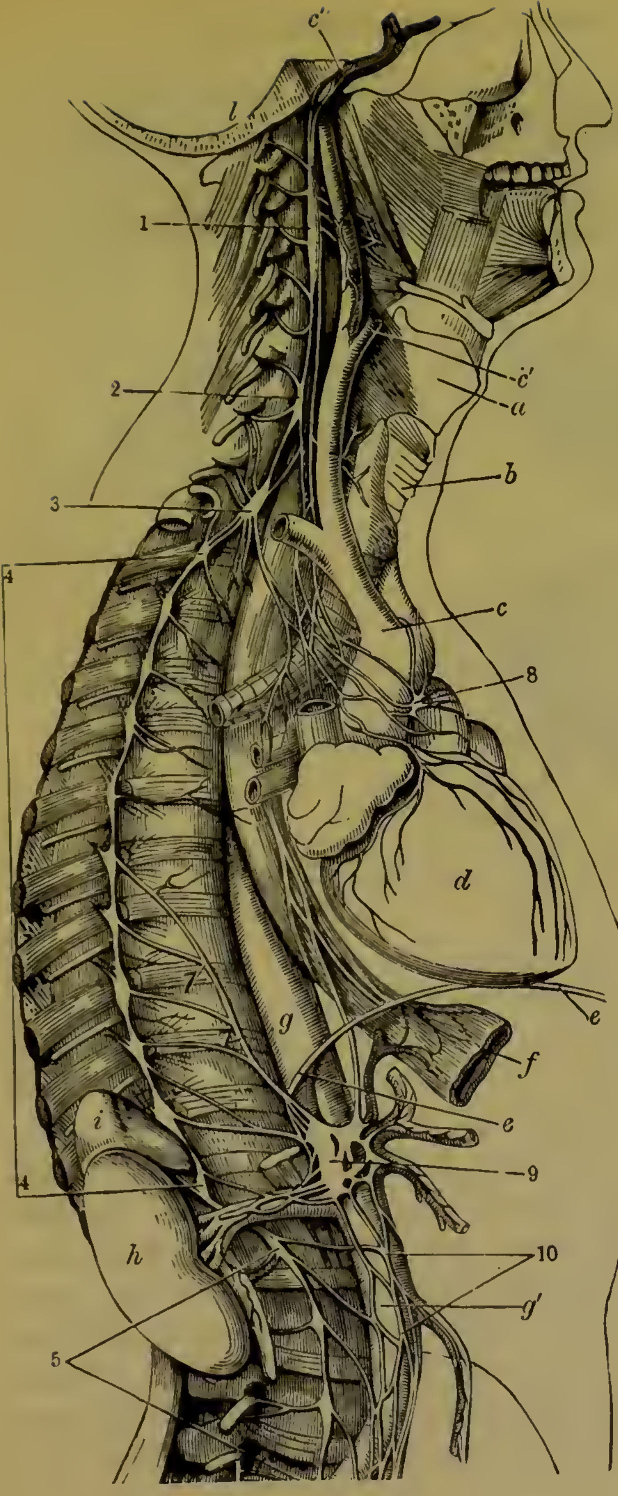


Fig. 163.

Greater Portion of the Sympathetic Nerve; the right lateral walls of the chest and abdomen, and the stomach, intestines, liver, spleen, and pancreas being removed to bring it in view:

1, 2, 3, the superior, middle, and inferior cervical ganglia; 4, the two lines from this figure include the twelve dorsal ganglia; 5, include the four lumbar ganglia; 8, cardiac plexus; 9, solar plexus; 10, aortic plexus; *a*, the larynx; *b*, the trachea; *c*, arch of the aorta; *c'*, external carotid; *c''*, internal carotid; *d*, the heart; *e*, *e*, the diaphragm; *f*, the cardiac end of the œsophagus; *g*, thoracic; and *g'*, abdominal aorta; *h*, the kidney; *i*, the supra-renal capsule; *l*, the section of base of the skull.

ideas. The organ of voice is the *larynx* (behind the *Pomum Adami*), the structure of which is complicated, and cannot be here described (fig. 163, *a*). It consists of various cartilages and muscles, the object of which is to tighten or relax the margins of two folds of membrane, called the *vocal cords*. By the vibrations of these cords voice is produced,

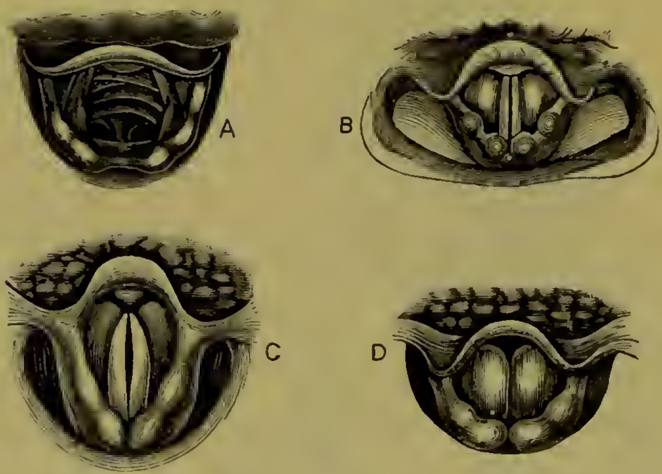


Fig. 164.

A, larynx and trachea on deep inspiration ; B, on phonation ; C, during falsetto note when only a portion of the length of the cord vibrates ; D, approximation of the ventricular bands or false cords as it occurs in straining the voice.

and by tightening or relaxing, separating or approximating them, we obtain various modifications of voice. When a high note is sounded, the cords are tense and close together (fig. 164, B) ; and, on the contrary, when we sing a deep bass note, they are relaxed and wide apart. The quality and compass of the voice differ in individuals. In men, the highest is the tenor ; the lowest, the bass ; the intermediate, the barytone. In women, the corresponding notes are the soprano, the contralto, and the mezzo-soprano. The difference between the deep bass of a man and the shrill soprano of a woman is that in the man the cords are longer and less tense than in the woman. At the time of puberty, more especially in the male, the larynx enlarges

from before backwards, thus increasing the length of the vocal cords. During the period of enlargement the voice 'breaks,' and the pitch, at the close of the process, will be found to be about an octave lower than at first. Consequently a boy who sang soprano now has a tenor voice, and one who sang contralto becomes a singer in the bass clef. A much slighter change occurs in the girl.

252. Speech is voice so modified by the action of the throat, tongue, cheeks, and lips, as to mean or indicate objects, properties, ideas, &c. This is *language*. If we breathe quietly, without causing the vocal cords to vibrate, and modify by the action of the mouth, &c., the volume of the air expelled, we produce *whispering*.

Questions.

251, 252. Distinguish between voice, singing, whispering, and speaking. Where is the organ of voice situated? What is the appearance of the glottis in inspiration, in expiration, and in singing a note? What are the various registers of the human voice? When the voice 'breaks,' why does it, in the male sex, fall about an octave in pitch?

INDEX.

(L. = Latin ; Gr. = Greek.)

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